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APPLICATION OF PERCEPTRONS TO PHOTOINTERPRETATION

FINAL REPORT
For Period 1 June 1963 to 1 July 1964
Contract No. Nonr 3161(00)
Report No. VE-1446-G-4
July 1964

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY, BUFFALO 21, N. Y.

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CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK 14221

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Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

TABLE OF CONTENTS

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

TABLE OF CONTENTS (Cont.)

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

LIST OF ILLUSTRATIONS

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

SECTION 1.0

INTRODUCTION

This report covers the period of 1 June 1963 to 1 July 1964 of a continuing research program at Cornell Aeronautical Laboratory, Inc. in the development of techniques for automatic recognition of features in photographs. This program has been sponsored by the Geography Branch of the Office of Naval Research under Contract No. Nonr 3161(00). Initial emphasis during this period was on preprocessing of original imagery to take advantage of present state-of-the-art capability in automatic pattern recognition. During the course of this period the four areas of technical concentration were (1) whole-photo classification, (2) object detection, (3) recognition, (4) system implementation.

1.1 Project Objectives

Objectives during this period were:

1) Long-Term Goal: Automatic scanning of large quantities of aerial photographs to remove those which are sterile: such as photos of cloud cover, empty ocean, or those containing no works of man.

2) Short-Term Goal: Invention, analysis, and trial of at least one technique on at least one type of discrimination, such as empty ocean vs. ocean containing ships.

During October 1963, the results obtained suggested that an operational aid to the human photointerpreter was within the reach of existing technology, so that the work was focused upon an experimental model of an optical-electronic device which measures spectral properties. The power spectrum of a picture segment is used as picture segment properties for an input to a pattern recognition device to accomplish one or more of the following:

1) Screening - Separation of sterile photographs from those containing areas of potential interest to human photointerpreters.

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2) Inventory - Detailed examination of a single photograph to count objects of a specific target class.

3) Rescanning - Selection of photographs which contain a specific target known only from one example.

1.2 Program Elements

Program elements were directed toward techniques which would provide early operational utility as well as to provide a reasonable amount of research of longer-term significance. These elements were:

1) Study of Property Derivation Techniques - Extraction of properties from photographic segments by optical spatial filters.

2) Recognition Studies - Design and economical implementation of a recognition system to perform the desired classification, with the CAL - IBM 704 digital computer as an investigation tool.

3) Design of Electro-Optical Spatial Filtering Equipment - Development of an optical-electronic machine of considerable potential power for investigating optical spatial filtering, and property extraction for selected photographic segments. Scanning systems were investigated which use closed-loop TV and Nipkow discs with an output integrator and display processing system.

4) Experimental Studies - Experimentation with two types of electro-optical filters. The ability of electro-optical spatial filters to derive properties useful for whole photo classification was demonstrated.

5) Long-Term Research - Investigation of research ideas which considered in addition to straight-line segments, the use of shadows for attention centering, curvature of brightness contours, and other methods of property extraction.

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1.3 Report Plan

This report will give the details of the past year (1 June 1963 to 1 July 1964) of research at CAL on Contract Nonr 3161(00). Primary emphasis will be on the experimental work on electro-optical spatial filtering, property extraction with the Mark III apparatus which was designed and constructed, the applications of the results to automatic photointerpretation, and the recognition experiments which processed actual photographs with the CAL IBM 704 computer.

1.4 Summary of Preceding Research

Phases I, II, and III of the research program for development of techniques for automatic recognition of features in photographs have been reported in a number of reports 7, 8, 10, and other background references 1, 2, 3, 4, 5, and 6.

Briefly, the Phase I, II and III objectives and accomplishments were as follows:

1.4.1 Phase I - April 1960 to November 1960[7]

Objectives

1) Determine feasibility of perceptron applications to photointerpretation.

Accomplishments

1) Used Mark I perceptron to demonstrate recognition of militarily interesting silhouetted targets.
2) Designed a Mark II perceptron.

1.4.2 Phase II - April 1961 to April 1962[8]

Objectives

1) Determine over-all system to work with perceptron photo-

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2) Isolation unusual requirements of system and prepare feasibility solutions.

3) Provide for a photo-input capability for the IBM 704 digital computer.

Accomplishments

1) Devised an over-all system diagram which recognized the importance of preprocessing of photographs prior to a recognition function.

2) Established the preprocessing techniques of detection, isolation and standardization.

3) Developed digital computer programs which implemented the detection, isolation, and standardization functions.

4) Provided a partial evaluation of preprocessing techniques.

5) Developed computer programs for implementing a large perceptron.

6) Developed 100 lines per inch, 16 level, photo-input system.

1.4.3 Phase III - April 1962 to December 1962[10]

Objectives

1) Establish feasibility of preprocessing techniques that were proposed and partially evaluated in Phase II.

2) Develop techniques for detecting low contrast objects.

3) Establish requirements of perceptron-like device to recognize objects of military interest which are detected by preprocessing system.

4) Demonstrate, using the programs implemented on the IBM 704, a complete, but simple automatic photointerpretation device which can identify five or more simple object categories.

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Accomplishments

1) Improved photo input facility.

2) Utilized photo output facility.

3) Developed hypothesis testing techniques for detection/isolation process.

4) Developed non-linear filtering techniques for gap filling.

5) Evaluated various preprocessing techniques by digitally processing a large number of photographs.

6) Established capability of a 500 A-unit perceptron to recognize noisy, militarily interesting objects.

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Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

SECTION 2.0

APPLICATIONS OF PHOTOINTERPRETATION

Early in the project year the relationship between potential automation of various photointerpretation tasks and operational employment of such automatic equipment was studied. Figure 1 is a chart which depicts one result of this study.

Shown in the figure are various levels of photograph, area, and object classification which could, at least potentially, be automated. Also indicated are specific outputs for operational uses of various kinds.

The figure is a functional classification diagram in which every triangular block delineates a classification operation while every square block describes the classified product of the operation. Ovoid blocks represent a useful product of one branch of the classification tree.

The study of this chart and related sponsor discussions led to the selection of three potential operational application areas which were to guide future research. These were:

1) Screening - Separation of sterile photographs from those containing areas of potential interest to human photointerpreters. A typical example of this application is the elimination of all photographs which contain nothing but cloud cover.

2) Inventory - Detailed examination of a single photograph to count objects of a specific target class. A good example of an application would be the counting of all the railroad cars in a set of photographs.

3) Rescanning - Selection of photographs which contain a specific target known only from one example. In this case detection of an object of interest in a photograph may create the desire to rescan photographs that have been previously rejected in order to find out more information about the newly detected object.

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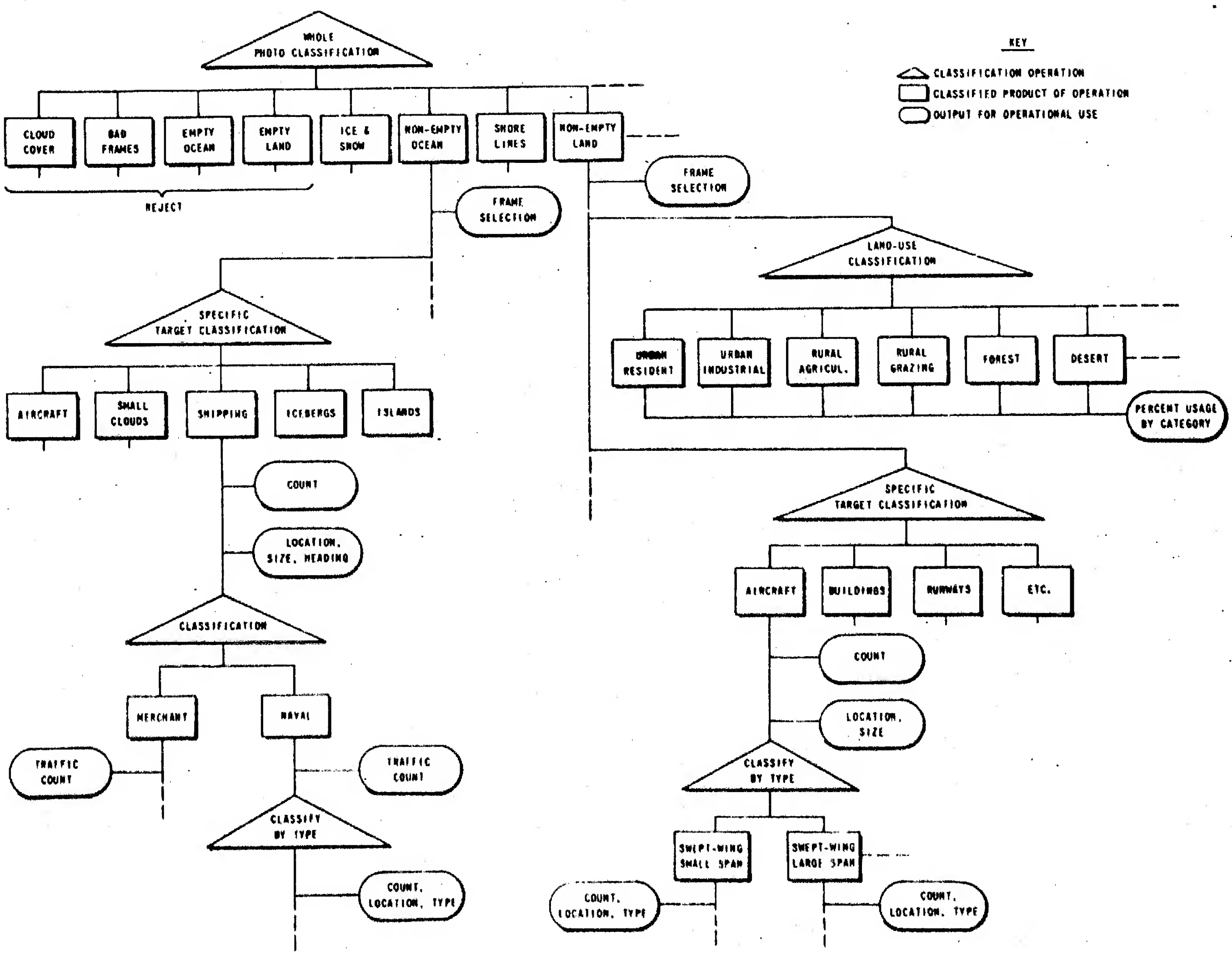

Figure I AUTOMATIC PHOTOINTERPRETATION OUTLINE

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With these applications in mind, research in property extraction using electro-optical spatial filters, recognition studies using general purpose digital computer simulations, investigation of problems in implementation of pattern recognition systems, and long-term research was initiated.

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SECTION 3.0

NUMERICAL FILTERING

Previous work in Phases II and III[8, 10] investigated two methods for detection and isolation of objects from the background clutter of a photograph which were: (1) the "annular" filter technique and (2) the Kolmogorov-Smirnov (K-S) brightness distribution test. Considerable information on the results of this portion of the preprocessing research is reported in the August 1963, CAL Report No. VE-1446-G-3.[10] Both of these methods were useful in isolating objects on a large number of photographs, but they missed some of the objects and there were problems with background shading. In particular, the K-S test was able to isolate a gray object from a mixed black and white background although the average intensity of the background was the same as the object while the annular filter technique worked for those cases where a difference in over-all intensity existed between the object and the background.

The current effort continued the investigation of a means for detecting objects by implementing two-dimensional frequency filtering on the IBM 704 computer. The basic method used is explained in a paper by Fryer and Richmond,[9] which was essential in reducing the calculation time for digital computer operations.

While the primary purpose of two-dimensional (2-D) filtering is for object detection, it was conjectured that it might also be of value for whole-photo classification, since the 2-D spectrum of various surfaces should differ (e.g., oceans from land).

A computer program was prepared for implementing a class of linear two-dimensional filters on the CAL IBM 704. The program was arranged to behave as any filter whose one-sided, one-dimensional transfer function is expressible as a second-degree rational function in the complex frequency plane without symmetry restrictions. The pictures are scanned with the CAL input facility flying spot scanner. The majority of pictures were processed with the facsimile scanner developed earlier on this program. This photo input system is limited to a picture resolution of 50 samples per inch in e

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The operation of the program was initially checked by using three filters; low pass, high pass, and band pass. These filters are related in that their frequency domain expressions have the same poles. The one-dimensional gain versus frequency curves for all three filters are shown in Figure 2. The frequency scale has been adjusted to agree with the reproduction scale of the output samples.

The two-dimensional filtering program was run on different type objects on various backgrounds. Examples presented here are for oil tanks on land, and ships at sea. The original photos with the respective outputs for the three types of filters are illustrated by Figures 3 and 4. Figure 3c and 3d show the absolute value of the filter outputs, since negative numbers cannot be accommodated by the output process. A bias equivalent to a medium gray has been added to the output to produce Figure 4b. A significant feature, or property of these filter outputs is the consistent areas of large output in the vicinity of the objects. This is shown by the black areas of Figures 3c and 3d and black and white for Figure 4b.

The filter output results are also significant for whole-photo classification since a properly chosen band-pass filter can be used to discriminate between large and small size picture anomalies (ships vs. waves) as shown by Figure 4b.

In summary, the following desirable properties can be stated for the band-pass filters.

1) Very low frequencies are removed, thus making the output independent of the average picture brightness.

2) Very high frequencies are removed, thus eliminating the effects of grain and quantizing noise, and other fluctuations small in scale compared to the objects to be detected.

3) The transfer function of the filters may be shaped to produce a large output for a specific range of object dimensions.

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

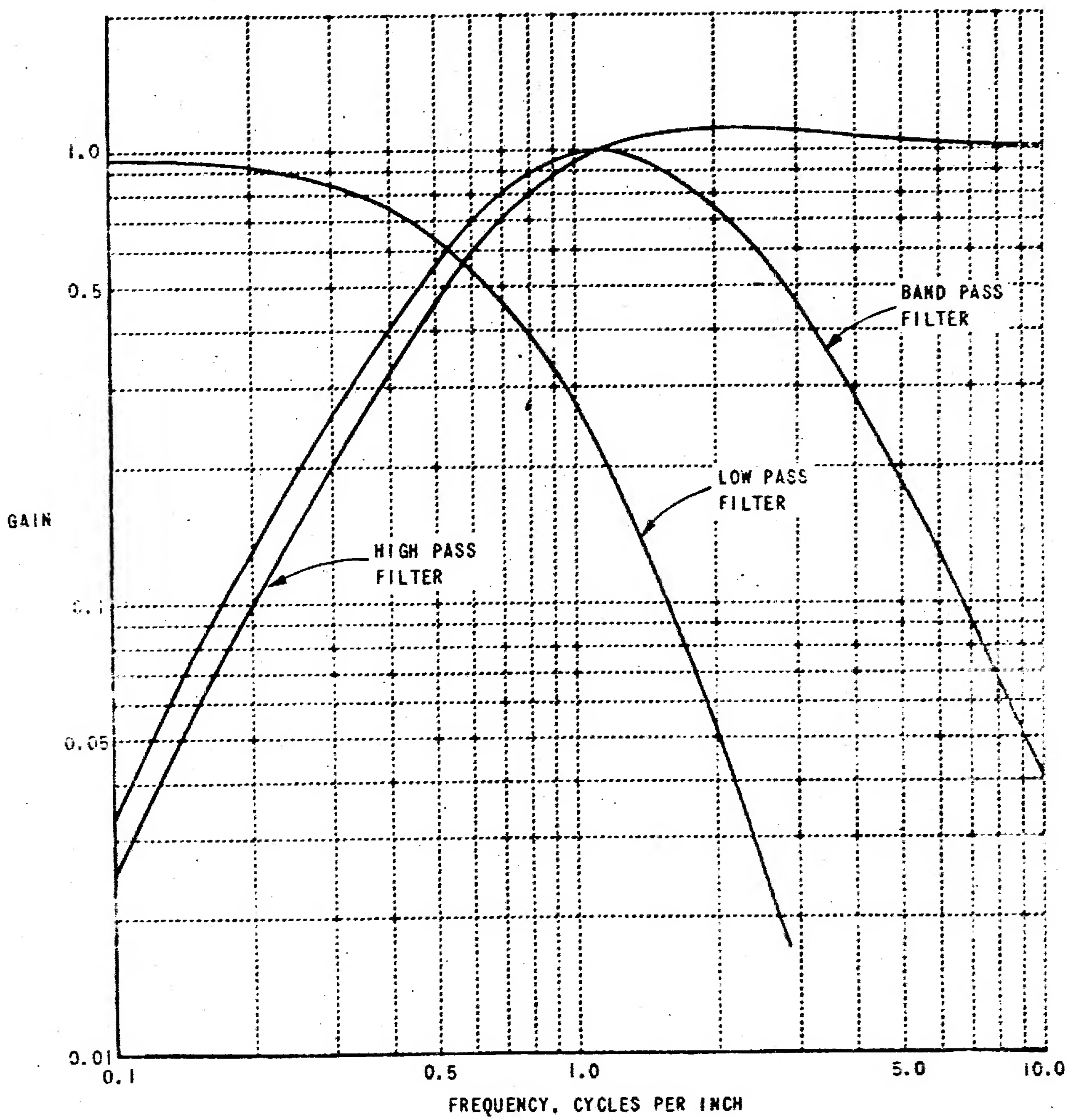

Figure 2 GAIN vs FREQUENCY FOR THREE FILTERS

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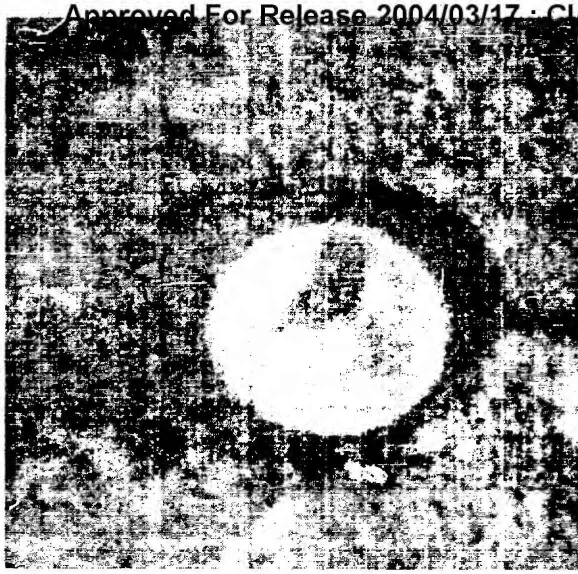

Figure 3a
INPUT PHOTOGRAPH
OIL TANK

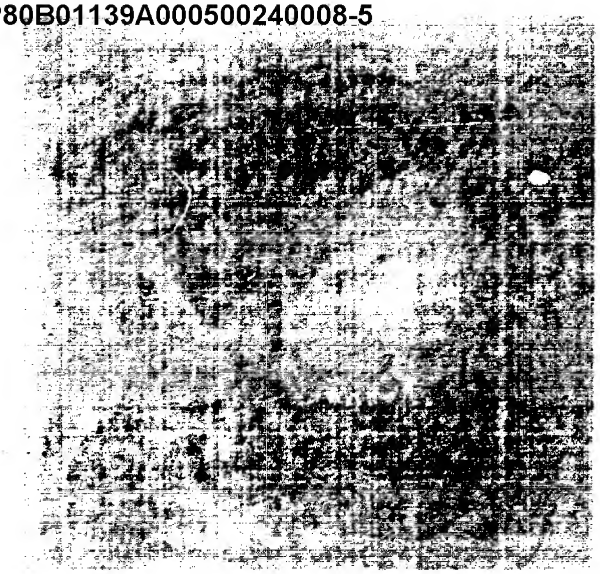

Figure 3b
OUTPUT OF LOW-PASS FILTER
APPLIED TO Figure 3a

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Figure 3c
ABSOLUTE VALUE OF THE OUTPUT OF
HIGH-PASS FILTER APPLIED TO Figure 3a

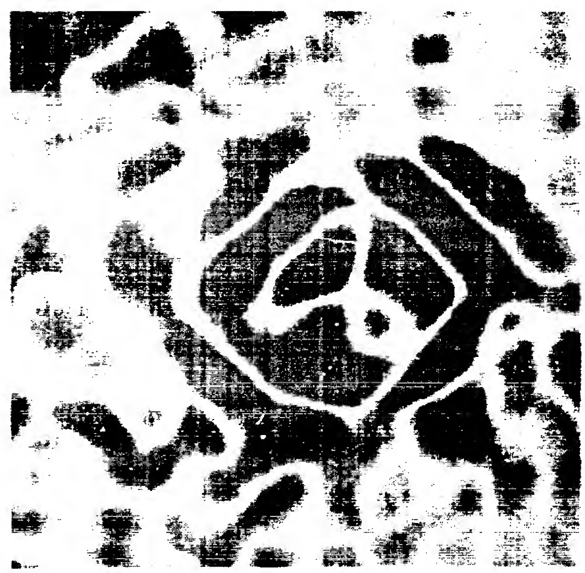

Figure 3d
ABSOLUTE VALUE OF THE OUTPUT OF
BAND-PASS FILTER APPLIED TO Figure 3a

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

3451

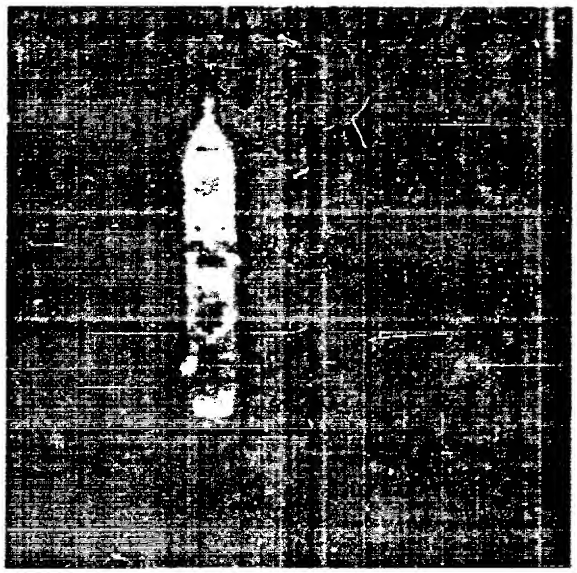

Figure 4a
INPUT PHOTOGRAPH
SHIP AT SEA

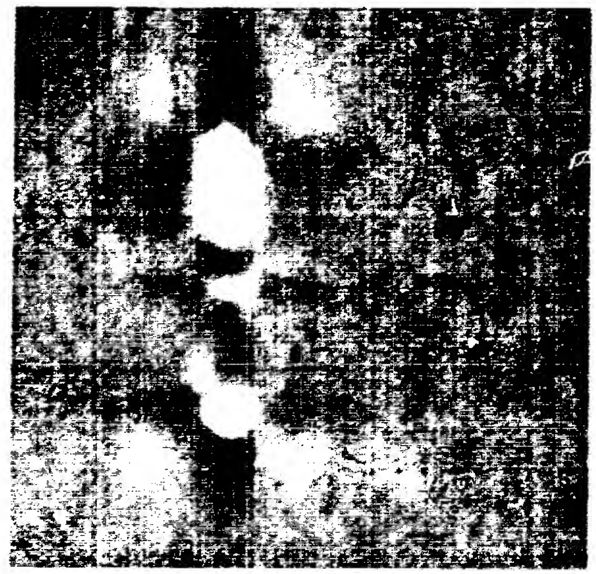

Figure 4b
OUTPUT OF BAND-PASS FILTER APPLIED
TO Figure 4a WITH BIAS ADDED

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The results which have been found for the combination of filtering processes can be stated as follows.

1) Distinctive outputs from some kinds of objects are certainly present in the output. More work is necessary to determine the nature of this distinctiveness.

2) The output is sometimes confused by the characteristic ringing behavior of band-pass filters. This can be corrected by averaging over larger areas.

3) The band-pass filters which were used are sensitive to orientation of unsymmetric objects. This has been traced to the computer technique used for implementing the band-pass filter.

4) A more direct method of implementing and testing filters would be desirable.

SECTION 4.0

ELECTRO-OPTICAL SPATIAL FILTERING EXPERIMENTS AND IMPLEMENTATION INVESTIGATIONS

The numerical filtering techniques discussed in Section 3.0 indicates that many useful properties can be derived from the two-dimensional power spectrum of elements of a photograph, but that a general purpose digital computer was not a good mechanism in which to implement these processes. The decision was made to investigate the use of electro-optical techniques for spatial filtering research, with the study specifically oriented towards the investigation of techniques for whole-photo classification.

During the course of this research two different electro-optical setups were used. In the first, which will be referred to as Setup "A," properties of the photographs were derived by processing electronically the two-dimensional power spectrum, whereas in the second, called Setup "B," properties of the power spectrum were derived by optical band-pass filters. In the first setup, the objective was to derive properties using spatial-filtering techniques that would be useful for whole-photo classification. As a result of the knowledge gained in these first sets of spatial-filtering experiments, the decision was made to develop the second spatial-filtering apparatus designed specifically for detecting culture (man-made objects) in photographs. This section describes the two electro-optical spatial filters which were used and the experimental results that were obtained from them. At the conclusion of this section, a survey of a few interesting implementation concepts for pattern recognitions systems is presented.

4.1 Implementation Requirements for the Experiments

In addition to the preprocessing and recognition characteristics which were desired from the experiments there were certain mechanical, optical, and electronic considerations which were established as "ground rules" or problems to overcome to achieve the desired results. These were as follows.

4.1.1 Mechanical Engineering Considerations

1. System Mechanics

   The system mechanical rigidity should be sufficient to allow only 500 micro-inches maximum displacement over the several foot length of the optical beam span. Static mechanics should permit mechanical repeatibility of experiments, especially of the source pinhole in the spatial frequency plane(s). The dynamic mechanics should be within the above limits for both excursions with the system frame and terrestrial vibrations coupled to the optical path elements.

2. Ambient Conditions

   An enclosed system should be used to reduce dust to a low level. Pressurized systems with electrostatically filtered air, or inert gas, would be adequate. The CAL white room removes 99.9% of the air particles in excess of three-tenths of one micron diameter, and has air conditioning for control of temperature and humidity. The temperature and humidity ranges would be established by equipment limits for expansion coefficients and condensation. (This constraint was later removed for the second set of experiments.)

3. Objective Monitor

   A full (or large fraction) display was required of the objective film during analysis with facility for highlighting certain regions. Dual systems, mechanical cursors, and beam splitters were considered.

4.1.2 Optical and Electronic Problems

1. A light source with good spatial (consider laser) coherence was required.

2. Good quality lenses (i.e., scratch and bubble free and with small aberrations) were necessary.
3. Good linearity and stability of the light collection, amplification, and thresholding system was necessary.
4. Fail-safe control to protect the photomultiplier was required.

4.2 Spatial-Filtering Experimental Setup "A"

4.2.1 Apparatus Configuration

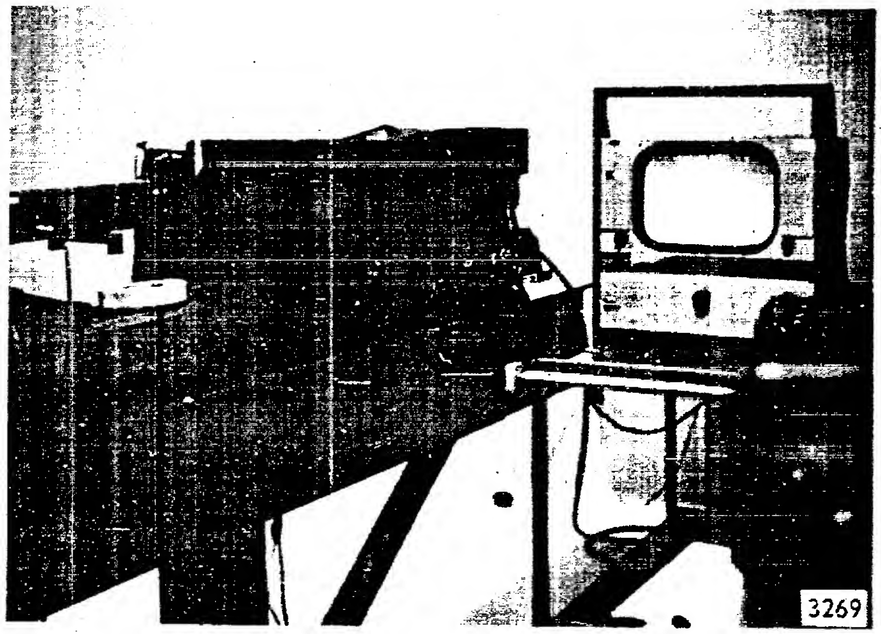
This experimental effort which was done with the assistance of optical processing specialists from the CAL Systems Research Department, took advantage of existing facilities. These included the White Room, and optical processing equipment which had been used previously on CAL Project CODART (Optical Spatial Filtering) under Contract No. AF 30(602)-2427 for Rome Air Development Center.[14]

The objective of Setup "A" was to display the spatial frequency plane of a portion of the stationary object film on a television monitor in order to evaluate properties useful for whole-photo classification. Electronic processing designs were studied (but not constructed) which would process the video signal by gating the display signal as determined by manually-set criteria referenced to the spatial frequency plane. The effort included: (1) setting up the experiment in the White Room with a mercury (Hg) lamp (later, a laser was used as a light source) and vidicon spatial filtering system, (2) performing qualitative measurements and calculations, and (3) studying electronic processing designs that would permit derivation of properties from the frequency plane.

The spatial filter experimental Setup "A" of Figure 5 was developed for laboratory investigations, and consisted of the following optical train:

a) A source of parallel monochromatic light.
b) An adjustable aperture which selects the size of the picture segment to be analyzed.

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5



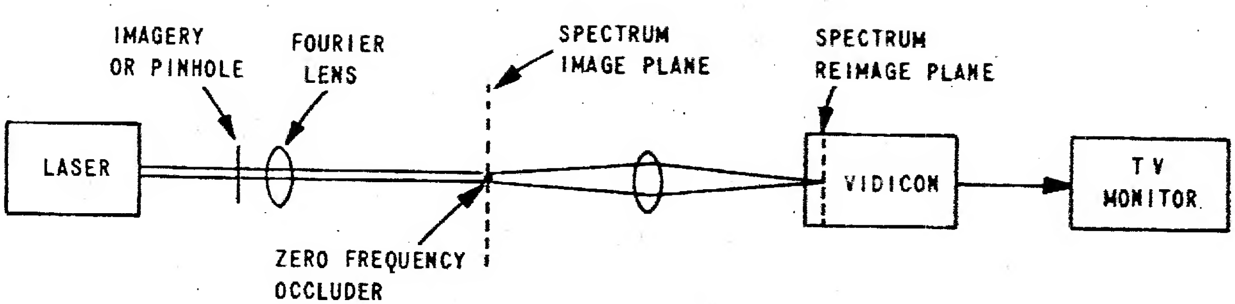


Figure 5 SPATIAL FILTER EXPERIMENTAL SETUP "A"

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c) A holder for the film frame to be analyzed, movable to select the segment position.

d) A converging lens to take the Fourier transform of the selected segment.

e) A television-type photo-sensitive device placed at the focal plane of d).

f) Scan-generation electronics, an output integrator, and display oscilloscope.

Since the output device is placed at the focal plane of the transformation lens, the power spectrum of the selected picture segment is directly available. Integration of this spectrum over any region of the two-dimensional frequency plane is possible by the use of standard electronic scanning techniques. Thus, the nature of the filter used can be varied by varying the scanning program. Dynamic adjustment by an operator while observing a display is possible. In addition, the output of a single filter from various picture segments can be readily observed.

In an operational application, a more elaborate scanning program can produce, in time sequence for a given area, the outputs of many filters. These can then be the inputs to a recognition device for classifying the area being examined.

The device as described has considerable growth potential, both as a laboratory device, and in application. One such possibility is the use of automatic control of the segment-selection apparatus as a result of previous recognition outputs. This would make possible various attention-centering, edge-tracing, and ribbon-following operations.

4.2.2 Optical Experiments and Calculations

A. Dynamic Range Experiments

In order to find the dynamic range necessary to electronically process power spectra, several power spectra were recorded on photographic film and the developed images were analyzed.

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The experimental work was as follows:

1) Films were exposed in the place where a vidicon would normally be placed.

2) Another piece of the same kind of film was given a set of controlled exposures.

3) The films were processed in the same way.

4) The processed films were scanned with a micro densitometer.

Figure 6 is a plot of density of control film versus exposure step. Each step has $\sqrt{2}$ times as much exposu·e as its predecessor. From inspection of the graph, it is concluded that over the range of interest, the density of the film is equal to a constant plus 0.8 $\log_{10}$ of the exposure.

The power spectra of the pictures have a general trend of decrease at higher frequencies. Superimposed on this is considerable fine detail. The dynamic range necessary to record the detail can be found by plotting upper and lower envelopes of the microdensitometer traces, and measuring the maximum density difference between them. The density difference, divided by 0.8, gives the difference in $\log_{10}$ of exposure, or the $\log_{10}$ of the exposure ratio. This number, when multiplied by 10, gives the dynamic range in db. (By envelopes are meant the closest smooth curves which include the trace between them.)

The distance between envelopes was measured directly from the microdensitometer traces. For the four scenes tested, the greatest distance was 1.17 density units, or 14.5 db.

The gradual trend of less power at high frequencies can be somewhat compensated by a prewhitening filter. A prewhitening filter matched to a signal whose power was proportional to the minus 2-1/2 power of frequency, i.e., 25 db/decade, was assumed. Reasons for assuming such a filter are: (1) the spectra of slits and rectangles go down at 20 db/decade, and of circular holes (asymptotically) at 30 db/decade, thus one would expect most man-made

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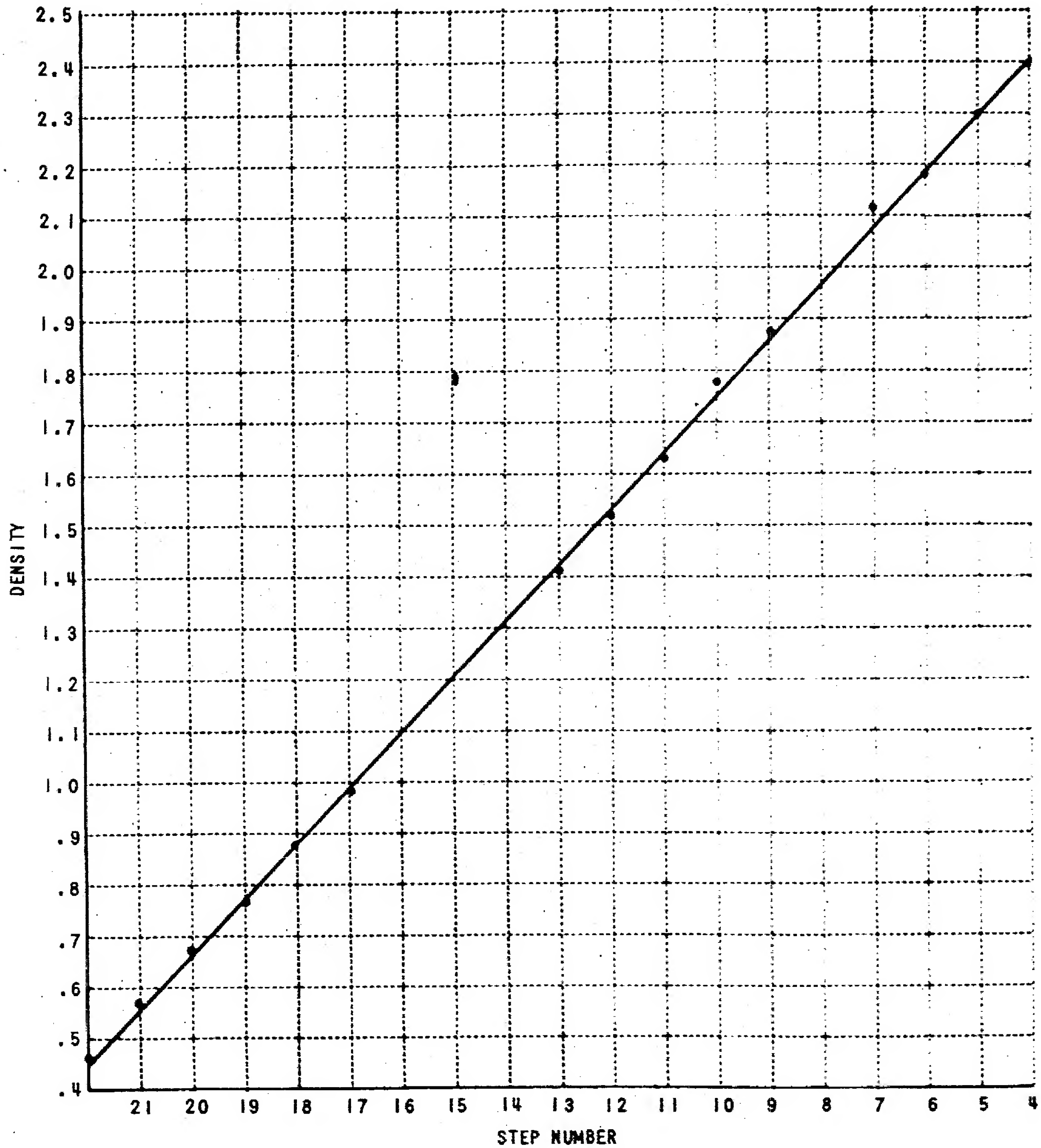

Figure 6 DENSITY OF CONTROL FILM vs EXPOSURE STEP

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objects to be in this range, (2) data obtained from another experimentor in which spectra of large areas were averaged over various orientation angles and which came out about 25 db/decade, and (3) the fair success in fitting the spectra discussed here with such a curve.

Given (1) the microdensitometer traces, (2) the results of the control exposure, and (3) the characteristics of the prewhitening filter, one can draw revised traces taking into account the attenuation of the prewhitening filter. The maximum and minimum for each revised trace can then be measured, and the maximum difference divided by .8 and multiplied by 10 as above. An equivalent graphical procedure was performed, and the results obtained are tabulated below.

Photograph Number	Type of Area	Range required
1	Bushes	15.0 db
2	Field	13.7 db
3	Parking lot	16.3 db
4	Railyard	12.5 db
5	Airy rings	13.7 db

(See Figure 9 of this section for reproductions of photographs numbers 1, 3, and 4)

According to tube manual data published by RCA, the dynamic range available from the 7735-A vidicon is 20 db. It can reasonably be concluded that in most cases sufficient dynamic range will be available. (If one assumes a normal distribution, 20 db is 4.4 rms deviations away from the mean of 14.24). Further, it is seen that little can be gained from attempts to design better prewhitening filters, because the greatest dynamic range required is 16.3, and even with a perfect one, 14.5 db would be required.

The spectrum of the photographic grain is usually taken as flat beyond the spatial frequencies of interest. For low contrast, grainy transparencies, the spectrum will level off at frequencies where the grain spectrum equals or exceeds the picture spectrum, destroying the usefulness of the prewhitening filter. Because the picture spectrum is small compared to the grain spectrum at these frequencies, it can be removed by an aperture stop

with negligible loss of information. Thus, grainy photographs will not cause dynamic range problems.

Calculations for the light levels and brightness measurements for the optical spatial frequency analyzer are given in Appendix A.

4.2.3 Electronic System Design for Spatial Spectrum Analyzer

This electronic circuitry is to produce the desired types of integration areas in the frequency plane. Special purpose logic equipment of conventional design, driven from comparators which use functions of the raster-scan sweep voltages as inputs, are used to derive a video gating signal during the time that the vidicon read-out beam is interrogating the desired raster areas. This is aimed at extraction of many spatial properties simultaneously for a single area in a photo. However, it has the drawback of requiring considerable electronic design and construction before any results can be obtained. An electronic processing system was designed for the spatial-filtering experimental set-up "A" of Figure 5 which consists of a variable-gain gate with controllable boundary conditions. In addition to the closed-circuit TV system, the design consists of control and comparison circuits, sweep and function generators, and a variable-gain, video-amplifier. The purpose of this portion of the system was to derive properties (e.g., determine the power in a specified high frequency portion of the spectrum of the photograph) by operations on the information in the two-dimensional frequency plane.

The operation of the electronic system will be described with reference to the block diagram of Figure 7. Shaded blocks represent components that are part of the closed circuit TV system.

Vertical and horizontal pulses obtained from the synchronization pulse separator are used to trigger vertical and horizontal sweep generators. The sweep voltages are squared and added and used to trigger comparison circuits 1 and 2. R_1^2 and R_2^2 are manually adjusted reference voltages. Assume R_2^2 is greater than R_1^2. Comparison circuit 1 will provide an

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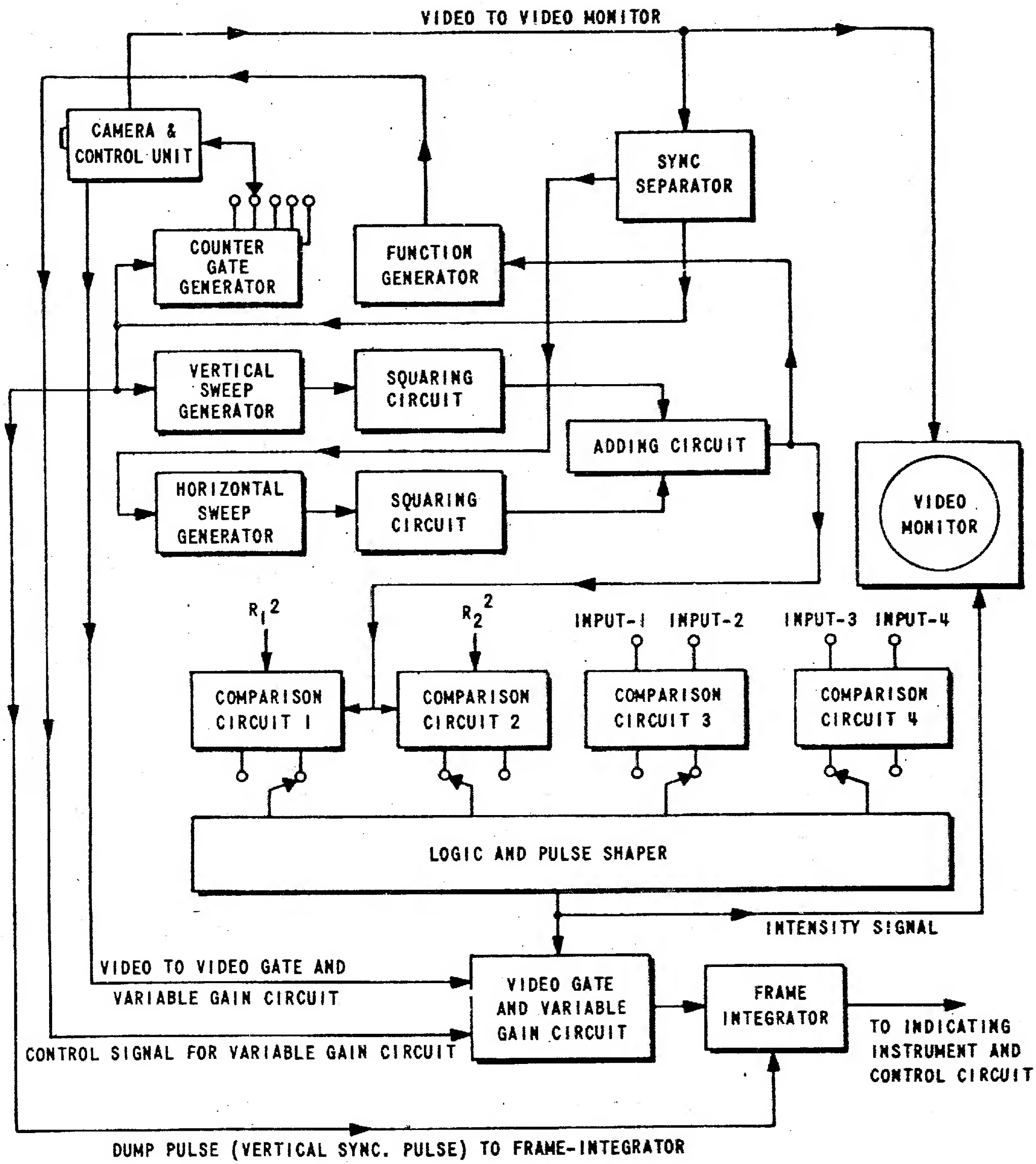

Figure 7 ELECTRONIC SYSTEM FOR SPATIAL SPECTRUM ANALYZER

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output pulse when the sum of the sweep squared voltages is greater than R_1^2 and comparison circuit 2 will provide a pulse when the sweep-squared voltage is less than R_2^2.

The comparison circuit outputs are applied to an AND circuit in the logic and pulse shaper block. An output pulse is obtained from the AND circuit when the scanning beam position on the TV raster has a radius vector between R_1 and R_2. This output pulse gates the video gate and variable gain circuit resulting in video appearing only within the annular region bounded by R_1 and R_2. Comparison circuits 3 and 4 are available for gating with other boundary conditions. For example, if equal amplitude sweeps are applied to inputs 1 and 2 of comparison circuit 3, video will be gated with a diagonal line on the TV raster as a boundary. The inclination of this boundary can be changed by varying the relative amplitude of the input sweep voltages. Comparison circuit 4 can be used in the same way resulting in video being gated within the sector bounded by two lines when both comparison circuits are used. All four comparison circuits can be used together to obtain video within the portion of a sector bounded by two arcs having radii equal to R_1 and R_2.

A variable gain circuit in the video gate can be used to multiply the video signal by a pre-set function of the position of the scanning beam on the TV raster. The gated video can be integrated over vertical scan periods and the output applied to recording and control circuits.

A counter, gate-generator circuit will be available for suppressing the vidicon scanning beam for a selected number of frames in order to permit video integration to occur in the vidicon tube. The video monitor can be used to view the ungated video picture. Portions of the raster which are gated on will be intensified on the monitor.

Critical circuits which will require experimental development are the variable gain and video gate, squaring circuits and function generator.

The variable-gain and video-gate circuit should function without degrading video bandwidth.* One method of accomplishing this involves a video amplifier with gating and control signals applied to suppressor grids of appropriate tubes.

The horizontal sweep squaring circuit requires high frequency squaring circuits and a diode shaping circuit appears suitable for the available sweep voltages (50 to 100 volts). A one quadrant squarer will require a horizontal sweep with $y = f(x) = f(-x)$ where x and y are horizontal and vertical displacements with respect to the geometric center of the raster. Similar considerations apply to the vertical sweep.

The function generator can also be a diode-shaping circuit, and if the required function is circularly symmetrical, the function generator can receive the radius-squared voltage from the adding circuit as its input.

Some circuit design work has been accomplished for some of the blocks shown in Figure 7, but will not be reported here in further detail.

4.2.4 Increase of Vidicon Sensitivity

In order to increase the sensitivity of the closed-circuit TV without making vidicon or internal circuit changes, a scan-gating method was proposed, but not implemented. This is a method of increasing vidicon sensitivity by decreasing the readout rate.

The charge pattern in the vidicon light sensitive plane is interrogated by a scanning beam. The current required to reset the light sensitive plane to the cathode-plus-beam-potential-drop voltage is a measure of the incident light since the last interrogation. Therefore, the vidicon sensitivity can be increased by decreasing the readout rate.

*Closed circuit TV systems usually have higher video bandwidths than entertainment models. A typical bandwidth for a closed circuit TV system is 8.5 mc. Vertical definition is also higher. The Kintel closed circuit TV has a 600 line raster. If the gated video is used only as an input to the frame integrator a lower video bandwidth may be acceptable.

This sensitivity increase is effective until the illuminated light-sensitive layer elements discharge completely. Sensitivity increases of several times to perhaps ten are possible. Dynamic range and signal-to-noise ratio are not greatly increased with the slow scan method.

Unblanking the cathode for only one raster scan out of several accomplishes a slow scan at high sensitivity without making internal changes in the monitor TV system, and would require only a small amount of external hardware. This external hardware would include (1) a four-bit, variable-modulus counter triggered by the TV-system vertical retrace, and (2) coupling elements and connectors to match the signal levels into the closed-loop TV system. The counter increments one state for each system frame (1/30 second) while the counter reset gate unblanks the vidicon cathode for one raster in N, for an N-state counter. The resulting sensitivity would be about N times the vidicon sensitivity obtained with continuous, ungated readout.

4.2.5 Results of Setup "A"

These experiments were designed to test the validity of the concept of a spatial filtering apparatus with a vidicon readout. Of particular interest were quantitative measurements of dynamic range and sensitivity requirements in addition to the properties useful for whole photo classification that could be derived.

Use of an appropriate pre-whitening filter has been shown to place the dynamic range of intensities in the frequency plane well within the capabilities of a vidicon. The combination of signal source power and vidicon sensitivity necessary to achieve reasonable resolution and signal-to-noise ratio in the frequency plane are within the state-of-the-art. Since more powerful lasers are announced frequently, it is not known whether a slow-scan vidicon must be employed for sensitivity enhancement. Such a decision must await a decision to build a specific equipment.

During the course of the measurements, photographs were made at the frequency plane of the TV monitor, and of the video signal for specific horizontal scan lines in the monitor raster. Figure 8, which used a rail yard objective film, shows typical results.

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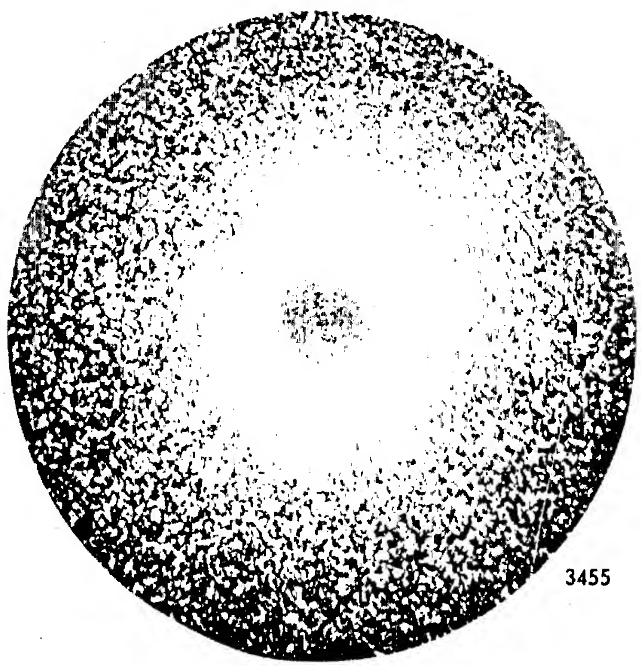
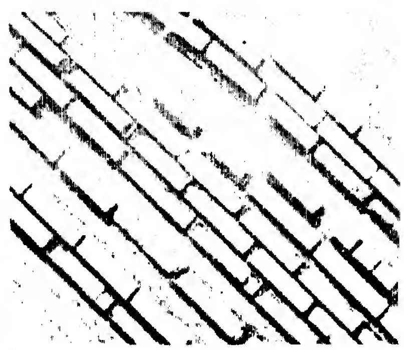
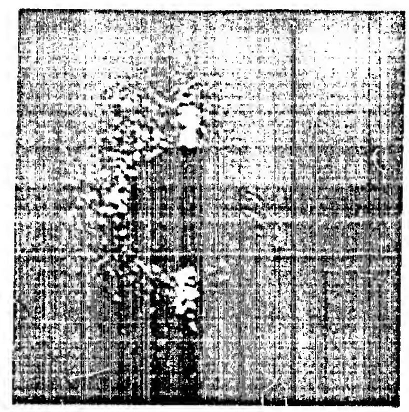


SPATIAL FREQUENCY FOCAL PLANE



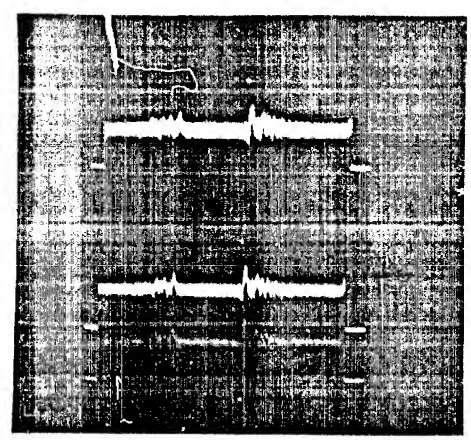
RAIL YARD PHOTO



TELEVISION MONITOR

Bandpass occluding filter used here (and in all the following examples) has a central stop disc of 5.8 mm diameter and a surrounding stop inside diameter of 37 mm; the passband is 7.3 cycles/mm to 47 cycles/mm.

The video signals correspond to the raster center line.



VIDEO SIGNALS OF HORIZONTAL SCAN LINES

Figure 8. RAIL YARD OBJECTIVE FILM PHOTOGRAPHS

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The general conclusion of these experiments is that optical spatial filtering apparatus using electronic readout via a vidicon can be constructed using current technology.

Several photographs of the TV monitor taken during the course of these experiments are displayed in Figure 9. Particularly striking in these photographs is the distinctly visible line structure caused by the man-made objects. Observation of these and similar photographs leads to the speculation that a culture can be detected by exploiting this line structure. This speculation lead directly to the experiments reported in the subsequent sections.

4.3 Electro-Optical Spatial Filtering Experimental Setup "B"

After the initial spatial filtering work began to show promise, it was decided to examine the possibility of culture detection in whole photographs using spatial filtering. The capabilities of the initial apparatus was extended using a slightly different philosophy for filtering in the frequency plane. In this case, an optical filter was used at the frequency plane of the spatial filter in place of electronic scanning and filtering of the vidicon. The optical filter could be easily changed or rotated to detect line structure. As before, a laser was used for a light source. This set up, as initially utilized, processed simple object transparencies with elementary filtering at the frequency plane. A modification of the initial configuration provided for a beam intensity reference level which was a function of the average density of the photograph. A discussion of the initial configuration and modified configuration of Setup "B" follows.

4.3.1 Initial Configuration

A block diagram of this setup is shown in Figure 10. The He-Ne laser output is collimated into a 2-inch diameter beam, and the Nipkow disc causes a raster-type scanning of the test transparency. A Fourier lens focuses the scanned light onto a wedge-shaped filter* for deriving spatial properties.

---

*Though this filter could assume any of a number of forms, the wedge shape was chosen in this case to detect straight line segments in the sub-elements of the photograph. A straight line in the object photographs (which is an indication of culture) will produce a spectrum in the frequency plane whose power is concentrated in a line perpendicular to the line in the input photograph. The center of the [illegible] low frequencies in the input photograph.

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BUSH FIELD

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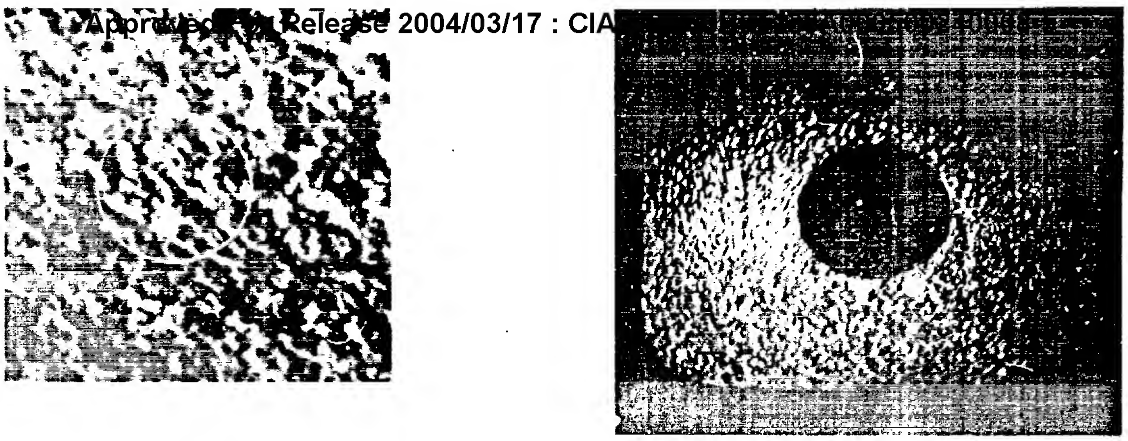
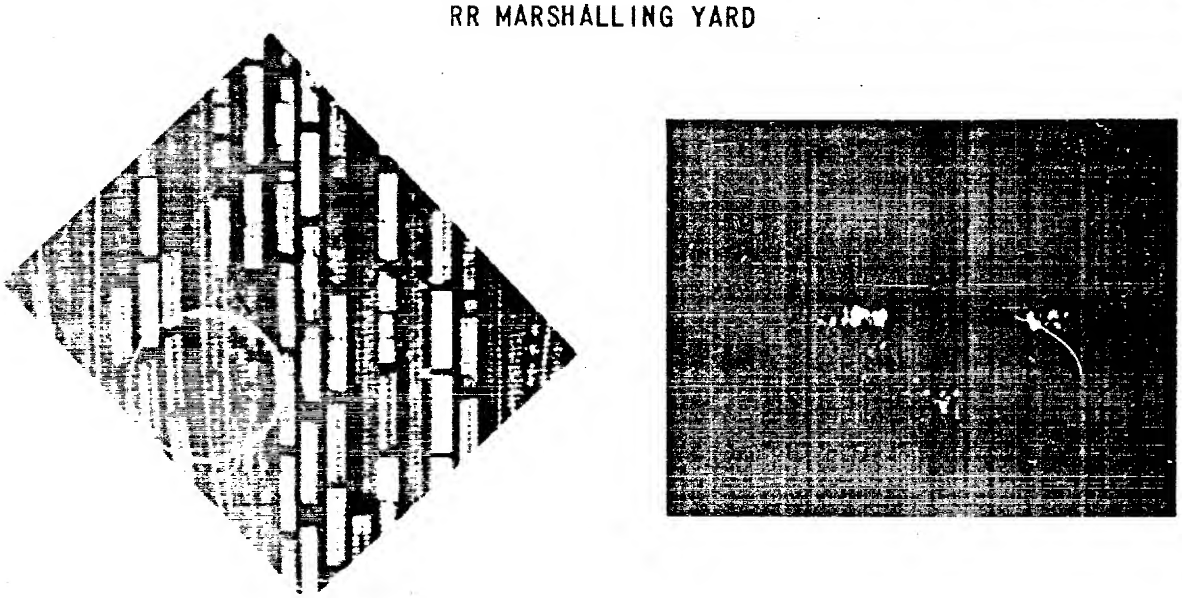
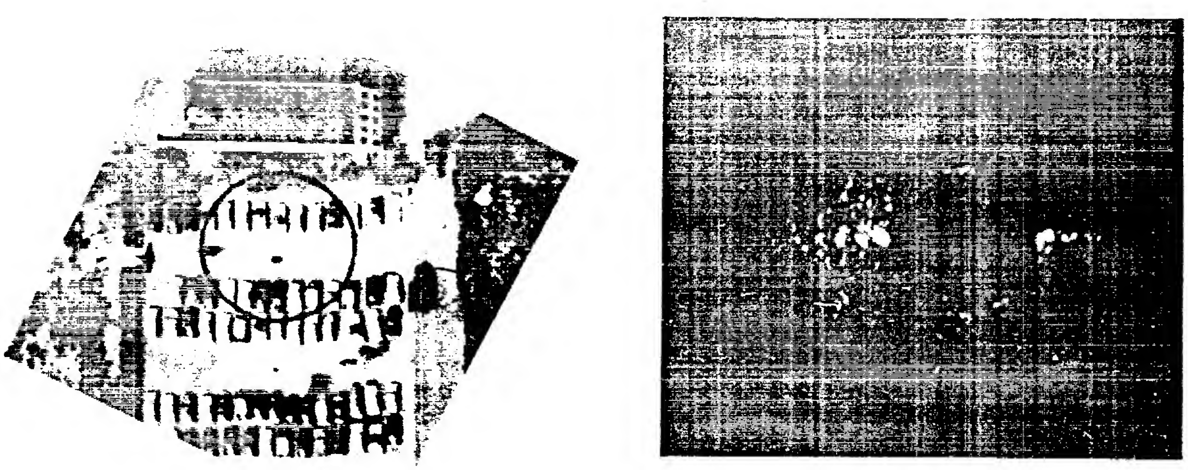


RR MARSHALLING YARD



PARKING LOT



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INPUT PHOTO

MONITOR IMAGE
OF SPECTRUM

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Figure 9 SPATIAL FILTER RESULTS

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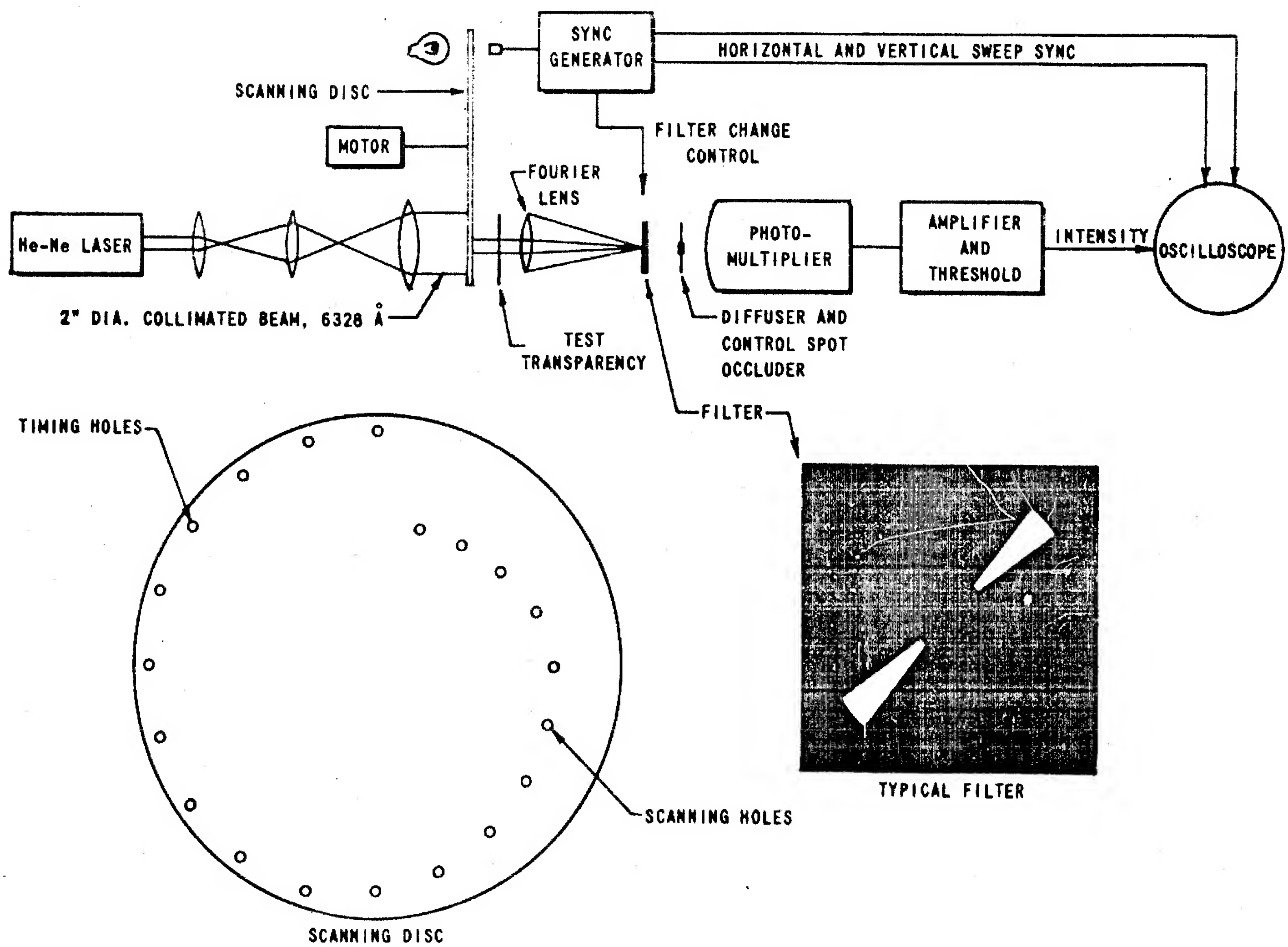

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Figure 10 BLOCK DIAGRAM OF ELECTRO-OPTICAL EXPERIMENTAL APPARATUS

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A photomultiplier light collection system has the greatest output when the transparency spectral lines coincide with the filter orientation. The photomultiplier output is amplified, threshold, and used to intensity modulate the beam of a CRT. Figures 11 and 12 are different photographic views of experimental Setup "B."

The following paragraphs describe the design of the initial configuration of the apparatus.

4.3.1.1 Scanning Disc Design

A Nipkow scanning disc[24] provides a 10 line raster over an active objective area of 1.5" by 1.5". Ten scanning holes (0.15" diameter) were placed on a spiral (regularly decreasing radii) and have ten synchronization holes diametrically opposite at a constant radius.

The scanning spiral was laid out using constant-arc length (1.5") between each scanning hole, rather than constant angles and decreasing-arc lengths. In either case, for a reasonably sized disc, the final CRO display raster would exhibit a keystone effect. With constant-arc lengths between scanning holes, the actual scan-line length remains constant for all lines of the raster, but the scan-line period decreases for shorter scanning hole radii. With constant angle differences between scanning holes, the scan line period would be constant, but the actual scan line length changes dependent on the line position in the raster.

The constant-arc length spiral design which was used provided a rectangular display with the addition of a raster line sweep generator whose slope (sweep rate) varied as a function of vertical position. This was more easily accomplished than compensating the objective films and the Z-axis signal to eliminate the display space keystone. Compensation was not implemented because the ±7% nonlinearity in the spatial display was not a large problem compared to lens quality, mechanical repeatability, and setup operation in the first experiments.

The disc was statically balanced and driven by a synchronous motor geared to 30 RPM.

A description of the control electronics for the scannin[illegible]

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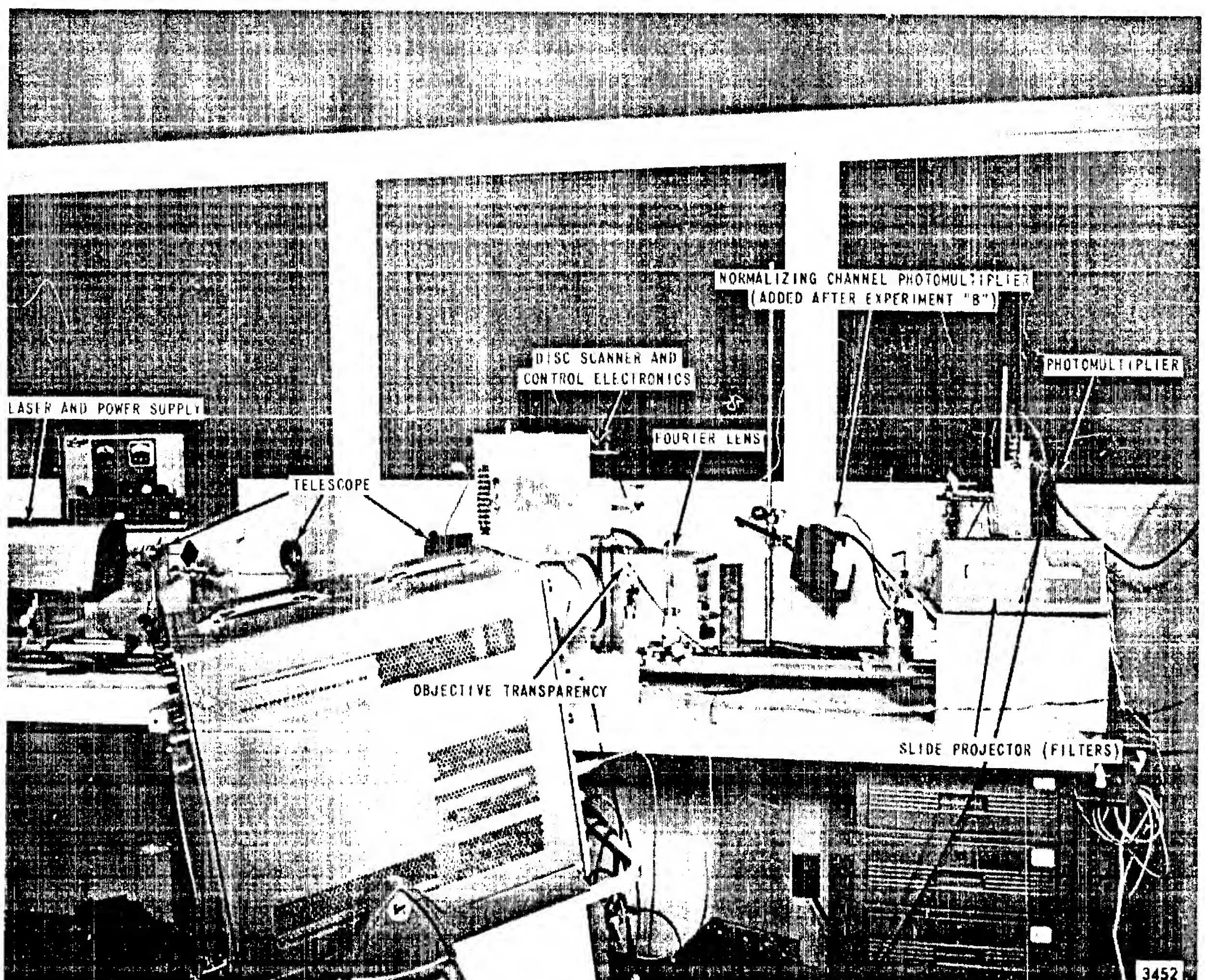

Figure 11 ELECTRO-OPTICAL EXPERIMENTAL SET-UP "B"

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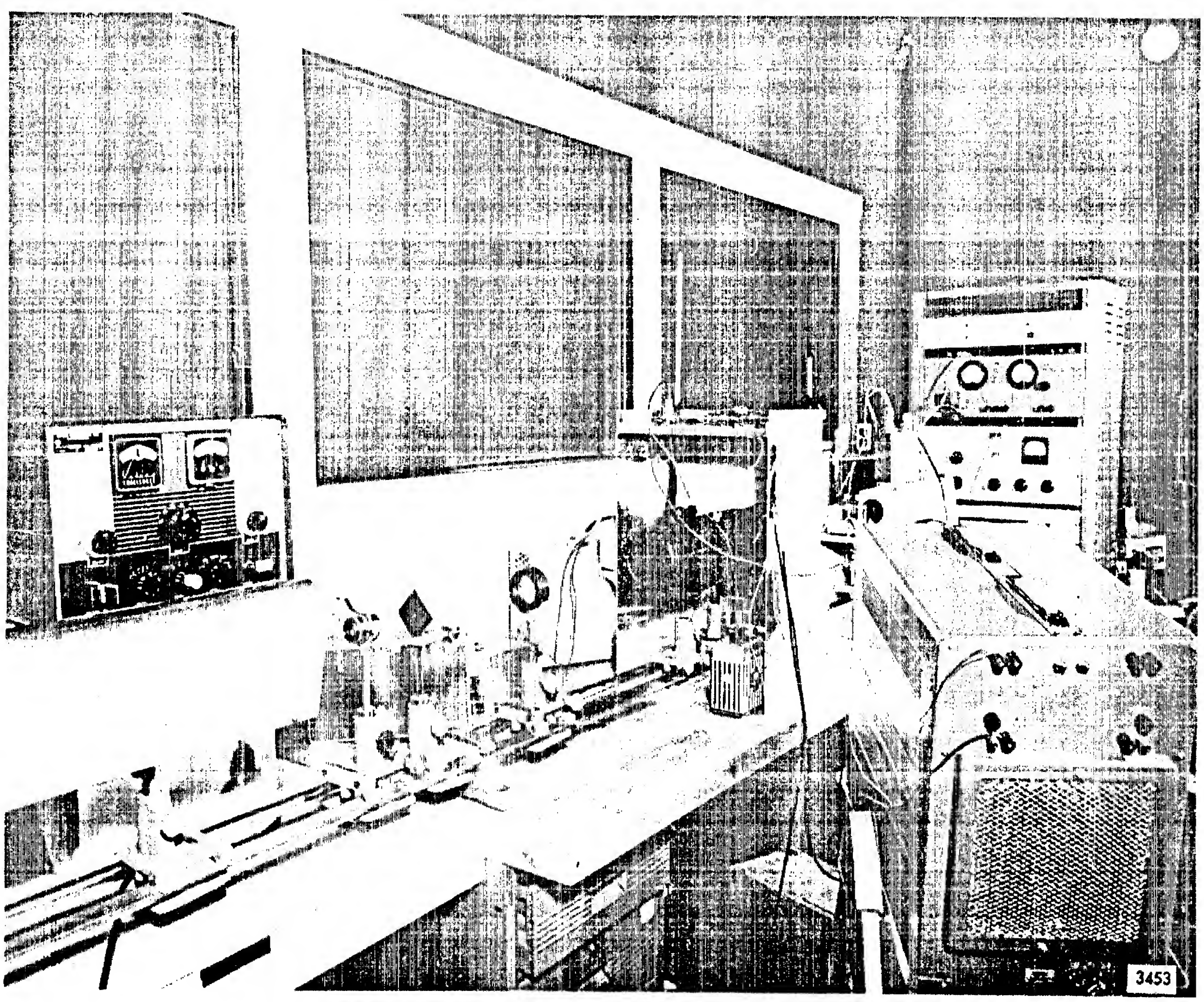

Figure 12 ELECTRO-OPTICAL EXPERIMENTAL SET-UP "B" (SECOND VIEW)

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4.3.1.2 Experimental Results Using Initial Configuration

Using specific 35 mm object slides (mostly opaque/clear drawings made up by a draftsman) as standard signal generators, several photographs of photomultiplier output voltage and the intensified display raster were obtained.

Three sets of photographs appear in Figure 13. These object transparencies used are the same ones used later by the modified configuration of Setup "B" (see Section 4.3.2). The video signals (top to bottom) and the intensified rasters (left to right) correspond to these object transparencies:

Condition	Object Transparency
A	Nothing
B	Applicable Test Pattern
C	Ronchi Ruling (100 line/inch)

No adjustments of amplifier gains, threshold, etc. were made for the measurements made within a set of photographs.

4.3.1.3 Problems Encountered with Initial Configuration

The following problems noted during use of the equipment are described here as follows:

1. Difficulty with mechanical repeatibility and stability. This includes lateral run-out of the scanning disc, movement of the optical bench and lenses due to vibration and shock, and repeatibility of object film and slide filter holders.
2. Light scattering from lens imperfections and the edges of mountings and lenses.
3. Drifts in laser mode and output level with time and temperature.

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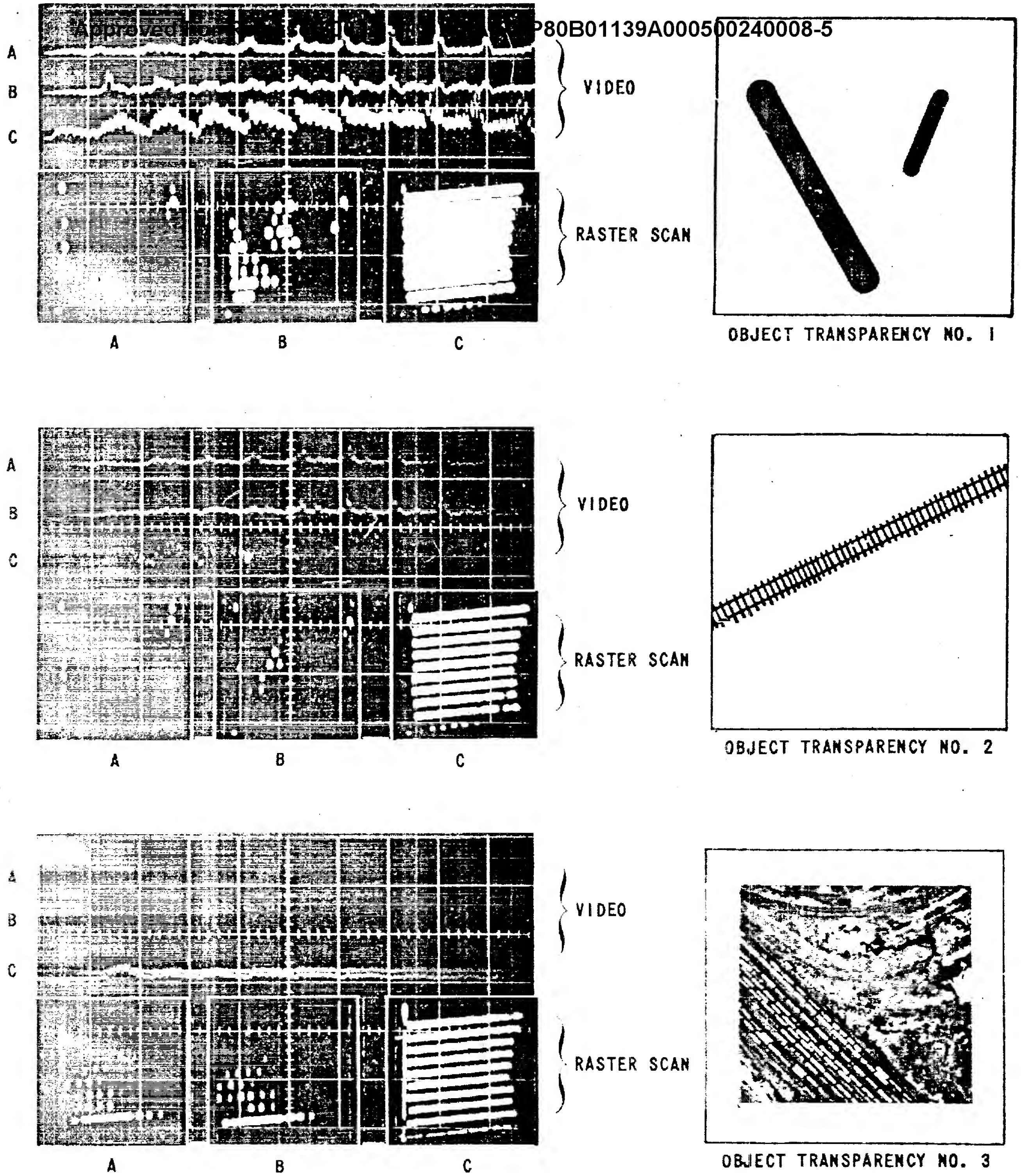

Figure 13 PHOTOGRAPHS OF VIDEO AND RASTERS CORRESPONDING TO OBJECTS SHOWN

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Because of these problems it was difficult to achieve good separation of responses for aerial photographs as contrasted with the Ronchi rulings and drafted transparencies used as signal generators. Additions and refinements were made to the system for the second set of Setup "B" measurements and produced better results.

4.3.2 Modified Configuration

4.3.2.1 Purpose

The experiments performed were a continuation of the initial Setup "B" described previously. The major change to the original circuitry was the generation of a beam intensity reference level which could be used in such a way that illumination variation across the aperture and average photograph density would not influence the filter output. The addition of low-pass filters in the photomultiplier outputs in order to more nearly match the signal bandwidth was another addition to improve performance. Experiments were performed with the three different object slides which were used previously.

4.3.2.2 Test Setup

The logarithms of the outputs from the signal photomultiplier and the beam intensity reference photomultiplier were generated by silicon varistors in the anode circuitry. After amplification and filtering the signals were subtracted and the resultant thresholded to yield the decision signal. A block diagram of the input circuit is shown in Figure 14.

The optical configuration is given in Figure 15. This portion of the system proved to be the most troublesome in obtaining consistent results. The Fourier lens (2-inch diameter) originally used, did not collect the light at the corners of the scan aperture. A 3-1/4 inch lens was located and substituted prior to Experiment No. 4.

An improvement of the reference signal waveshape was accomplished by insertion of a translucent paper two inches in front of the photomultiplier. The photomultiplier and translucent sheet were positioned

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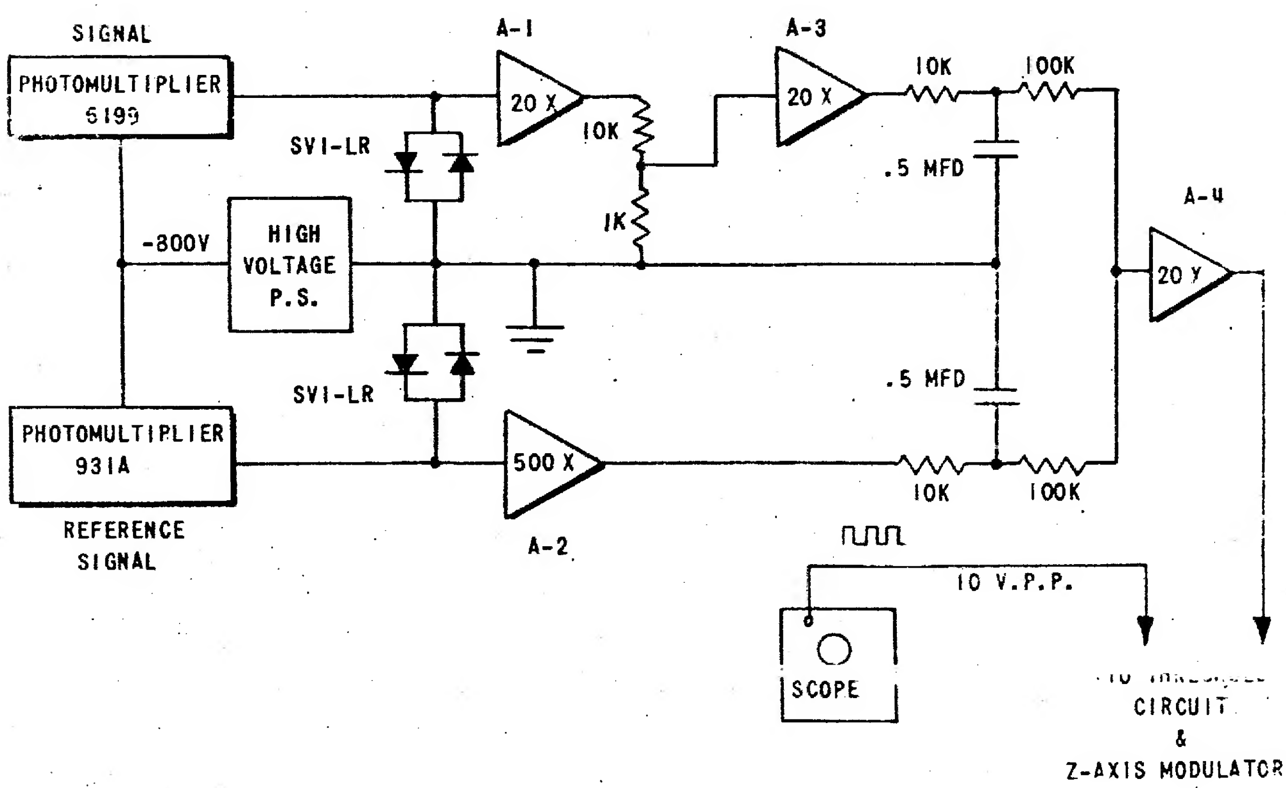

CIRCUIT PART	DESCRIPTION
A1, A2, A3, & A4	KIN TEL, D.C. AMPLIFIER IIIA & GAIN SETTING
SVI - LR	VARISTOR, LINEAR TO LOG CONVERTER

Figure 14 BLOCK DIAGRAM OF THE MODIFIED INPUT CIRCUIT CONFIGURATION

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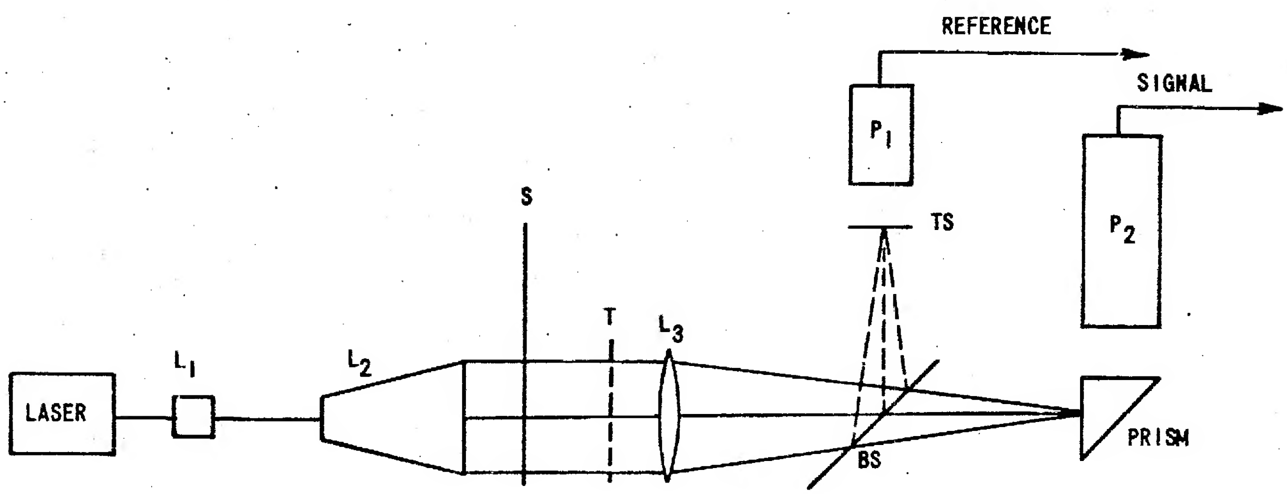

SYMBOL	DESCRIPTION
L_1	LENS - 25 mm, F 1.5
L_2	LENS - COLLIMATOR
L_3	LENS - FOURIER
S	SCANNING DISK
T	OBJECT TRANSPARENCY
TS	TRANSLUCENT SHEET
BS	BEAM SPLITTER
P_1	REFERENCE PHOTOMULTIPLIER
P_2	SIGNAL PHOTOMULTIPLIER

Figure 15 OPTICAL CONFIGURATION FOR MODIFIED SET-UP "B"

such that the light image was focused to a point at the plane of the translucent sheet. It was noted that the occluding spot in the signal light path was not completely opaque. Time did not permit an evaluation of the effects produced by light leakage through the occluding spot.

The scalloped right edge of the raster (Figure 16) appears to be associated with errors in the horizontal trigger timing waveform. This means that the horizontal scope trace start time is not synchronized with the horizontal position of the scanning light beam. An attempt was made to correct this problem early in the experiments by the adjustment of the scope horizontal scan time. The scan speed was increased so that a square raster was observed. It was later apparent that the horizontal position distortion was severe with considerable loss of signal at the lower and upper scan lines.

The optical arrangement was identical for all experiments except the replacement of the two inch Fourier lens with a 3-1/4 inch lens for Experiment No. 4. The electronic arrangement was identical for all experiments except for adjustments of the threshold level potentiometer and oscilloscope controls. The amplifier gain settings are indicated on Figure 14. The "Anded" calibration signal from the scope was set at 10 volts p.p. during the course of all experiments.

4.3.2.3 Experimental Results

The photographs which are shown here represent photomultiplier output and display raster signals for the three object transparencies under different conditions. The equipment setup was identical to the Setup "B" tests of paragraph 4.3.2 except for addition of a beam-intensity reference-level circuit. Performance was critical and subject to threshold level settings and oscilloscope trace triggering. Experiments No. 1, 2, and 3 did not have the best settings of Z-axis modulation threshold and oscilloscope triggering. The 35 mm object slidesfor Exps. No. 1, 2, and 3 show respectively (1) two diagonal cutouts, (2) a railroad track, and (3) an actual railroad yard photograph. The video signals on each photograph correspond to the raster scan condition shown below and follows this format. These are all shown on Figure 16.

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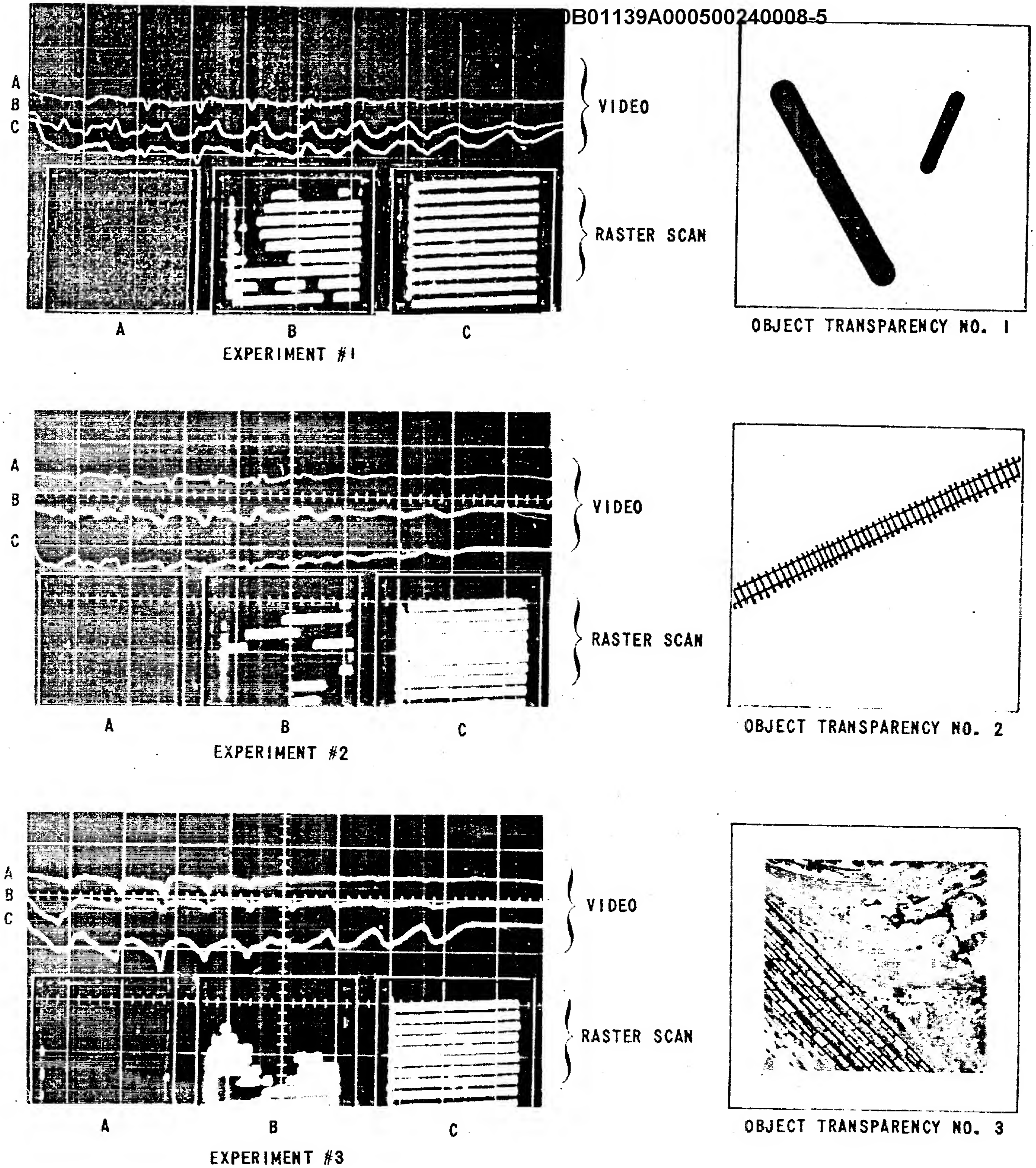

Figure 16 OBJECT SLIDES, CRO VIDEO TRACES AND RASTER SCANS FOR EXPERIMENTS #1, 2 AND 3

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Condition	Object Transparency
A	Nothing
B	Applicable Test Pattern
C	Ronchi Ruling (100 line/inch)

1) Experiment No. 1

On Figure 16, the Experiment No. 1 object slide of diagonal lines is shown together with the video and raster scan photographs. There were no adjustments of amplifier gains, threshold or other settings within the set of photographs A, B and C for this or other experiments. The results of raster scan B do not show a clear outline of the object slide as expected because of a low-threshold level setting for Z-axis modulation and improper CRT triggering.

2) Experiment No. 2

The conditions here were similar to Experiment No. 1 except for the railroad track object slide and Raster Scan B shows false triggering with more of the trace intensified than expected.

3) Experiment No. 3

The threshold control was very sensitive to adjust for this test and the object slide of the actual railroad yard photo [illegible] poor contrast as indicated in Figure 16 by the similar appearance of video traces B and C. The object slide culture in the lower left hand corner does not appear to be accurately represented by Raster Scan B, but generally corresponds to the area of culture.

4) Experiment No. 4

The results of this experiment are shown on Figure 17 and used the same object slide as Experiment No. 1. The Raster Scan B shows the best result of any experiments with the modulated raster being a clear representation of the object slide. This was taken after the threshold level was raised and the CRT trigger sensitivity adjusted.

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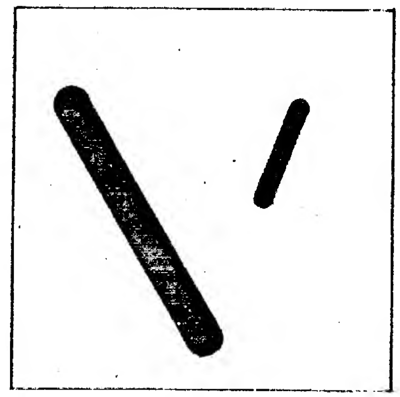
OBJECT SLIDE



CRO RESULTS

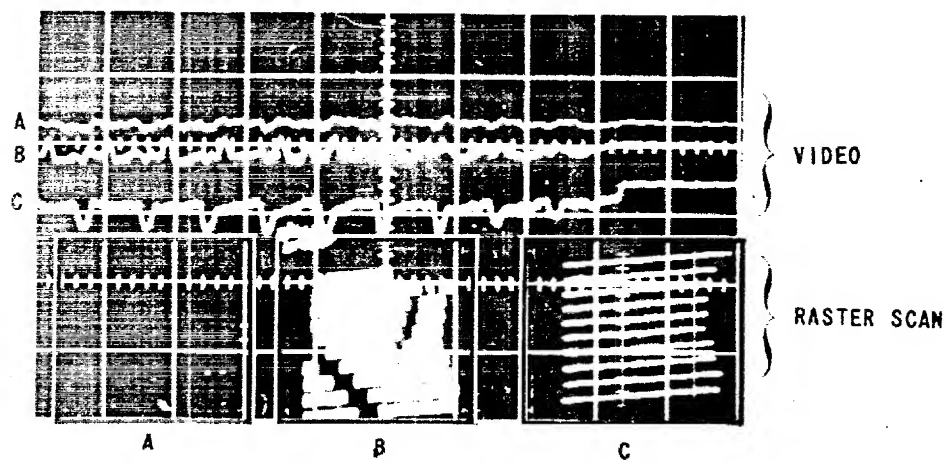


Figure 17 OBJECT SLIDE, CRO VIDEO TRACES AND RASTER SCANS FOR EXPERIMENT #4

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4.3.2.4 Conclusions

Exp. No. 4 (Figure 17) shows that the approach considered in these experiments is potentially capable of detecting straight line structure in photographs. The earlier runs (No. 1, 2, and 3) demonstrate the value of careful threshold and scanning linearity adjustment, and of the larger Fourier lens.

Subsequent to these reported results, the threshold level was raised and a raster signal of a brightly outlined object was obtained, but not photographed. Unfortunately, a dc-amplifier failure occurred before this result could be recorded. The amplifier was not repaired before the experimental effort had to be terminated.

4.4 Survey of Implementation Processes and Techniques

Early in the program a survey was conducted of new optical and optical-electronic technology[14, 15, 16, 17, 18, 19, 20, 21, 22, 23] which could have applicability to more specific directions later in the program; and were related to the image enhancement, culture detection, and recognition functions.

4.4.1 The specific topics in the survey included:

1) types of recognition systems
2) spatial (2-dimensional) optical filters[14, 23]
3) optical-electronic linear discriminators[21]
4) optical correlators
5) types of storage media[19]
6) methods for background discrimination[22]
7) electro luminescence

4.4.2 Processes and Techniques Considered

More emphasis was placed on the following items because of their interest to the desired processes and the present state of technology.

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A. Photochromic Materials

Photochromic effects[19] were investigated as a possible adaptive component technique for optical processors. The transmittance could be "trained" using intense sources and interrogated at low intensity. Lack of grain is a desirable characteristic while the presently available slow response-recovery cycle rate is a disadvantage.

B. Correlators

Correlation was investigated as a possible means for optical recognition processes. Correlation can be done by optical defocusing and subtraction using either (optically) polarized filters or electronic processing. While this has possibilities, it was not pursued further in view of other processes.

C. Spatial Filtering

The derivation of specific aperture filters which simulate differential operators is a means of providing channels sensitive to lines, edges, and shapes. Time-varying filters offer an added variable winnowing and inventory of large area photographs. Various types of lasers[15,16] and light sources were investigated for use with spatial filtering and other optical processing.

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SECTION 5.0

RECOGNITION

5.1 Objective

The long range goal for the recognition studies made for Project PICS is to provide recognition apparatus which will become a part of an automated photo-interpretation system. It was felt that this long range goal could best be served at present by experiments leading to a better understanding of a perceptron as a two-dimensional pattern recognition device, especially with respect to trade-offs among sensory to association unit connection density, organization of these connections, and number of association units.

5.2 Results

As described in a summary of earlier work on Project PICS,[10] the use of the perceptron to recognize objects contained in a photograph has been based on the assumption that previous operations have been performed (such as the use of the "annular" filter or the Kolmogorov-Smirnov filter) which detect and then isolate objects. These isolated objects are then presented to the perceptron as black silhouettes on a white background and in a standard size and orientation.

5.2.1 Recognition and Training of Distorted Objects

In order to test the ability of the perceptron to recognize such isolated objects, a set of 720 training patterns and 720 testing patterns had been constructed in an earlier phase of this study. These objects represented various types of aircraft and other sorts of objects, and were distorted in a process which introduced a type of pseudo-random noise into their outlines, causing irregularities similar to those in objects isolated from photographs by the "annular" filter or Kolmogorov-Smirnov filter.

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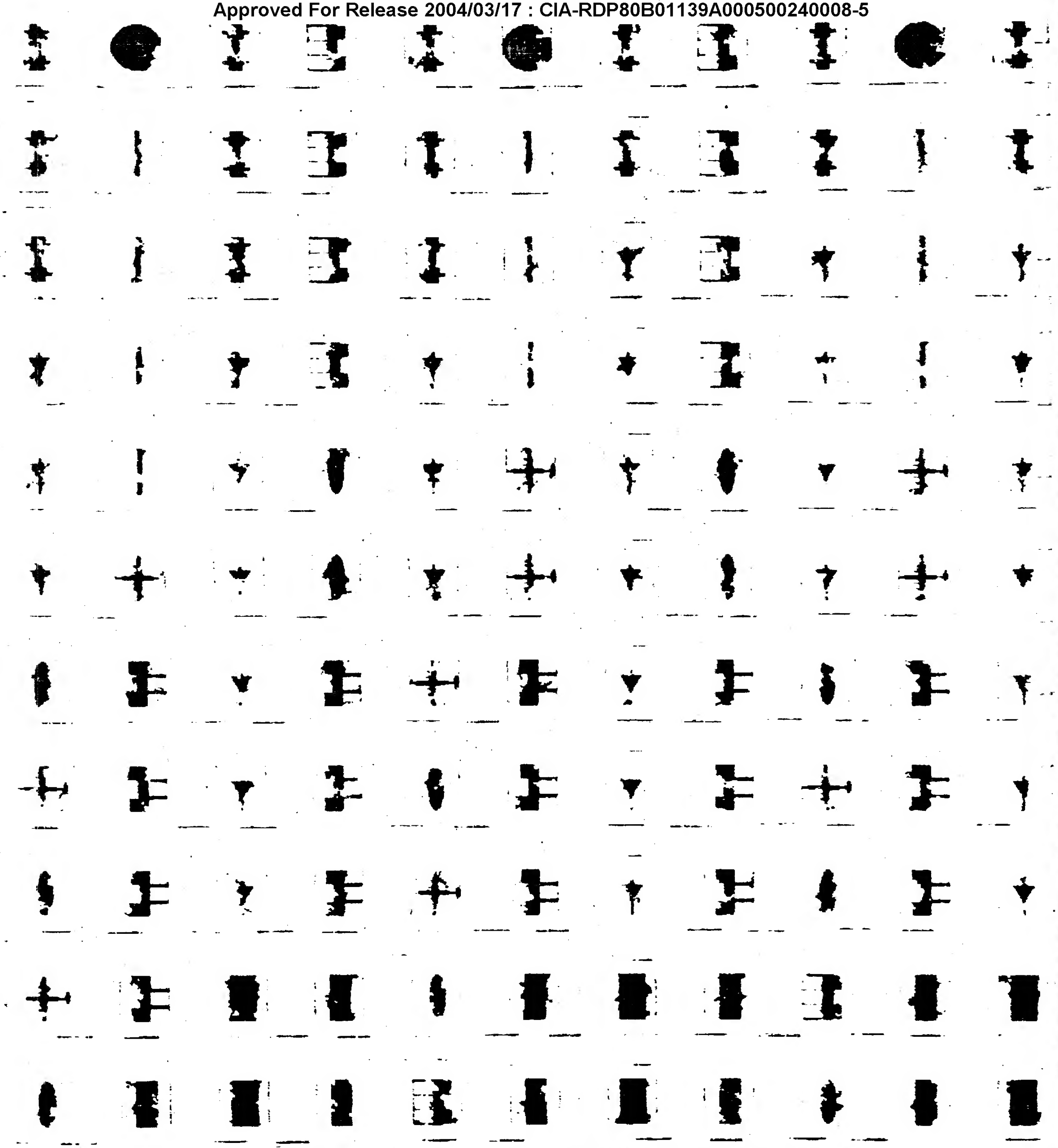

Figure 18. SAMPLE OF OBJECTS USED IN RECOGNITION EXPERIMENTS

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Figure 18 illustrates a portion of these distorted patterns which were used for training. It contains some of each of the classes (TU-104's, IL-18's, LA-60's, F-102's, ships, storage tanks, and rectangular buildings) as well as the abstract shapes, ellipses of moderate eccentricity and very long narrow rectangles comprising the non-object category. Though patterns in the testing and training class were statistically similar, no one pattern in the training class duplicated in the testing class.

In the earlier work on the project, the results shown in Table 1 had been obtained when testing with the 720 patterns in the test set after first training the perceptron to 100% recognition on the training set of the 720 similar, but not identical patterns. As shown in the table, the lowest individual performance figure was the 95.5% correct recognition capability for identifying rectangular buildings. For all other object categories, the recognition rate was in excess of 98%. The over-all object detection probability figure is 98.7% and the false alarm rate in these experiments was 3%.

In a simpler classification experiment with the same patterns, the four different types of airplanes, TU-104, IL-18, LA-60, and F-102 were put into one class and all the remaining patterns into the other class. With this grouping of patterns the perceptron achieved 100% recognition of the test set after first being trained on the training set.

These experiments were all carried out with a single size perceptron having 500 A-units, and 20 positive and 20 negative connections to each A-unit.

5.2.2 Comparison of Perceptrons with Adaline

During the current extension of the project a parametric study of the perceptron was made and the performance of the perceptron was compared with that of a single layer perceptron-like device called an Adaline.[13] Figures 19 and 20 summarize the results of this study. When a 500 A-unit perceptron was trained to distinguish all the airplanes from all the other objects in the set of 720 patterns, and was then tested on the 720 different examples of the patterns in the test set, it recognized all the patterns correctly. When the same test was made with an Adaline, the Adaline made 6 errors in the test set, giving it a recognition rate of 99.2%.

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Table I a
RESULTS OF RECOGNITION EXPERIMENT

SYNTHESIZED OBJECTS

CORRECT PATTERN CLASSIFICATION	TOTAL NUMBER	NUMBER CORRECTLY CLASSIFIED	NUMBER INCORRECTLY CLASSIFIED	% RECOGNITION
TU 104	60	60	0	100.0
IL 18	60	60	0	100.0
LA 60	60	60	0	100.0
F 102	60	60	0	100.0
SHIPS	60	59	1	98.3
BLDGS.	90	86	4	95.5
TANKS	60	59	1	98.3
OBJECT TOTAL	450	444	6	98.7
OTHER	270	262	8	97.0

OBJECT DETECTION PROBABILITY = .987

FALSE ALARM PROBABILITY = .030

Table I b
COMPLETE RECOGNITION RESULTS

CORRECT CLASSIFICATION ↓	RECOGNIZED AS								
	TU 104	IL 18	LA 60	F 102	SHIPS	BLDGS.	TANKS	OTHER	REJECTED
TU 104	60								
IL 18		60							
LA 60			60						
F 102				60					
SHIPS					59				1
BLDGS.						86		4	
TANKS							59	1	
OTHER					2	6		262	

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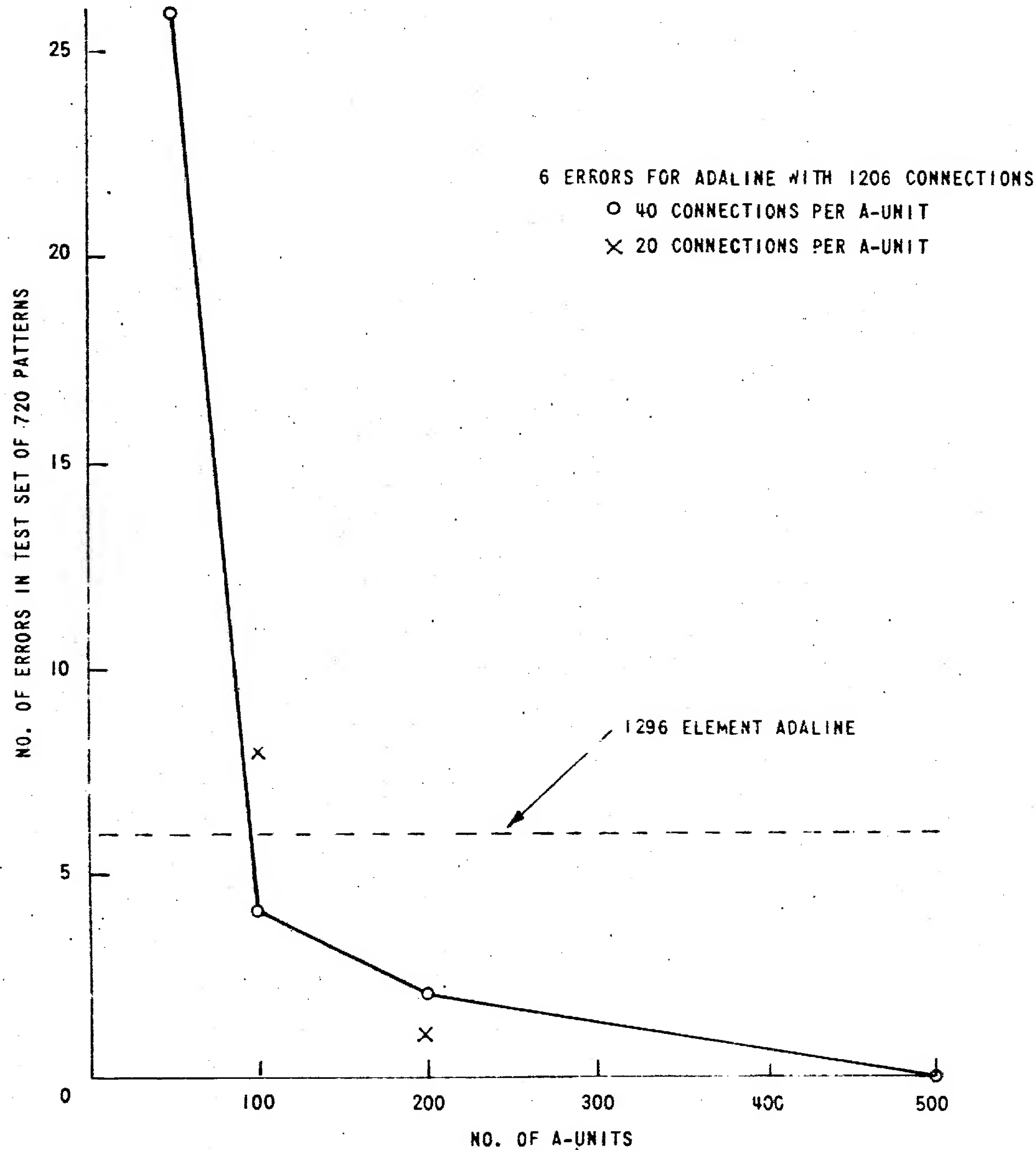

Figure 19 SIMPLE CLASSIFICATION. COMPARISON OF PERCEPTRONS WITH ADALINES

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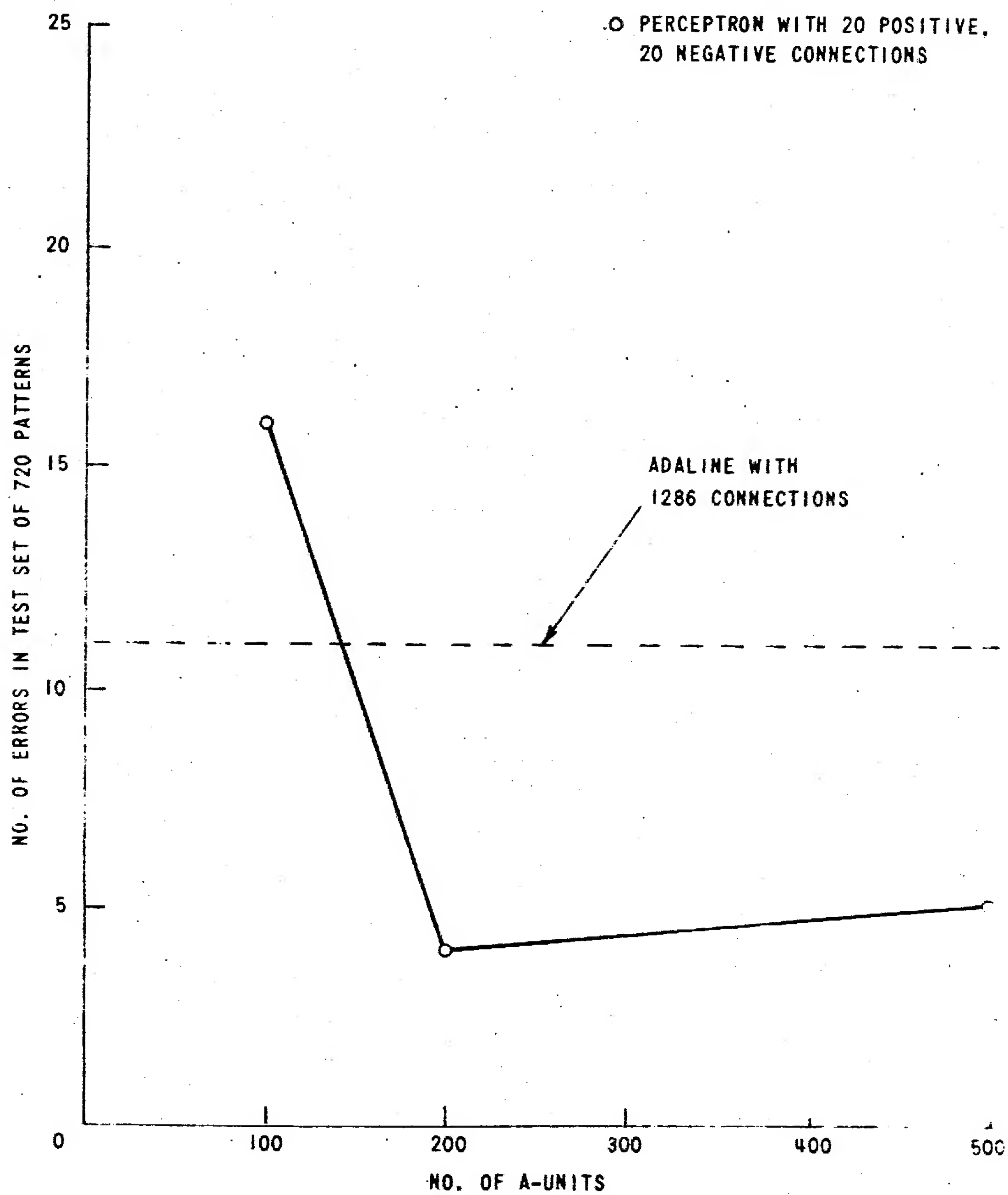

Figure 20 MULTIPLE CLASSIFICATION (INTO SIX CLASSES). COMPARISON OF PERCEPTRONS WITH ADALINES

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Smaller size perceptrons were tested to determine what size would have a recognition performance equivalent to that of an Adaline. These tests showed that a perceptron with about 100 A-units, and with 20 to 40 S to A connections per A-unit had a roughly comparable performance. Such a perceptron would require 100 weights and from 2000 to 4000 connections. This compares with the 1296 weights required for an Adalines using the 36 by 36 matrix in which the patterns were quantized. Tests were also made comparing the Adalines and perceptron when the objects were classified into 6 different classes including 4 different types of airplanes, a class of ellipses having a shape resembling ships, and a class containing all other objects. The Adalines achieved a performance of about 98.5% recognition on this more difficult task, and the comparable perceptron size was about 100 A-units, as before.

5.2.3 Final Recognition Study

In a final study related to recognition performance, the synthetically generated patterns which were previously used for recognition studies (see Figure 18) were used in a new set of experiments to obtain the effects of the additional distortions produced by the isolation and standardization processes. These additional distortions are produced because the figures are often torn into several pieces by the noise generation process.

A 500 A-unit perceptron was trained to recognize all aircraft in a large sample of these patterns. A different set of 866 patterns was used to test its performance. There were 42 classification errors (4.8%) in this experiment. This is to be compared with no errors in a set of 720 patterns in previous experiments which did not use isolation and standardization.

Upon examination of the types of errors which were made, it seemed possible that inclusion of a scale-factor objective property would lower the error rate. An experiment showed that this was a false hope. Hindsight indicates that the patterns which were not aircraft were both smaller and larger than the aircraft and thus a scale factor property could not aid linear separability.

5.2.4 Measure of A-unit Performance

Another study undertaken in the recognition portion of the project was concerned with developing a measure of individual A-unit performance. Such a measure was felt to be valuable for two reasons. First, it might provide a more economical means of making parametric investigations of the perceptron, such as the one described above. Second, it might provide a valuable tool making possible various self-organizing techniques for improving A-unit performance by making changes in S to A connections, or simply by selecting those A-units which were measured as having a high performance.

Such a measure of A-unit performance, based on the concepts of information theory, was described in a paper by Lewis.[12] This measure gives, in effect, the rate at which an A-unit is transmitting information about the classification of the pattern, and makes use of the joint probability distribution of A-unit activity and pattern classification. A program was written to calculate this quantity for individual A-units, and it was determined that the amount of information being transmitted varied considerably from one A-unit to another. Some A-units were transmitting no information, while others transmitted as much as .38 bits of information per pattern in making the discrimination of airplanes from all other objects. In this discrimination, slightly less than 1 bit of information would be required to correctly identify each pattern.

The high variability of transmission rate from one A-unit to the next suggested that it might be difficult to obtain an average value for a single type of A-unit, as would be required for a parametric study, because a very large number of A-units would have to be used to obtain a reliable average. On the other hand, the high variability in information transmission rates clearly indicated that self-organizing techniques which made use of this sort of information could make substantial savings in the complexity of a perceptron built to perform a particular recognition task.

For example, the measurements of A-unit transmission rates might be used to implement a self-organizing system which would carry out an A-unit selection scheme on two levels, first varying parameters to

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determine the best type or types of A-units to generate by using a "hill-climbing" technique in conjunction with the average transmission rate for the group, and then having selected a type or perhaps several types of A-units, the best individual A-units within that type could be selected.

5.2.5 Method of Optimizing A-units

Another possible self-organizing technique, which could either be implemented in conjunction with those just described, or separately, would consist of optimizing individual A-units by systematically varying their S to A-unit connections, thresholds, etc. For example, having used the previous process to select several good A-units, first generation descendants of these could be constructed which resembled the parent A-unit in all respects except that a single S to A-unit connection might be moved right, left, up or down, by one square, or the threshold moved up or down by 1. Transmission rates would then be measured for all descendants, and the best descendant in each family would be chosen. Using these, a second generation of A-units could be constructed, and the same process repeated several times until little or no further improvement in transmission rates was achieved.

However, because of the increased emphasis which was placed on techniques closer to the stage of implementation as a practical aid to photo-interpreters, these self-organizing techniques were not investigated further.

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

SECTION 6.0

CONCLUSIONS

The research effort during the past year for the application of perceptrons to photo interpretation has been successful in accomplishing major research objectives. Recent experimental results in electro-optical spatial filtering have been particularly encouraging for indicating feasibility of using the two-dimensional frequency spectrum of a photograph subelements as a source of properties for whole-photo classification.

Major areas of accomplishment during the past year have been as follows:

6.1 Numerical Filtering

Two-dimensional spatial filtering can be performed by numerical techniques in a general-purpose digital computer. This implementation method is not as straightforward as the use of optical spatial filters, and has some inherent limitations. The principal result of this line of investigation was to alert the investigators to the detection and classification possibilities inherent in the output of spatial filters.

6.2 Electro-Optical Spatial Filters

Experimental investigations were carried out which emphasized several optical-electronic spatial filtering methods for extracting properties which would be useful as recognition process inputs. Previous to that, a survey of state-of-the-implementation methods was undertaken which, among other things, brought attention to optical-electronic spatial filtering. The spatial filtering of set-up "A" using a laser for a light source produced photo results of the power spectra of selected images. Significant differences are noted between man-made and non-man-made objects suggesting that properties could be derived for culture detection and whole-photo classification.

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

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The second experimental set-up "B" was useful for indicating feasibility of a technique based upon the electro-optical spatial filters as property-measuring means. The light which scanned the test transparency was collected by the photo multiplier and displayed on a CRT as a raster. The presence of objects in the raster, as expected, indicated that filters properly oriented could be used to detect line segments in an image. Outputs from a set of filters would produce properties that could serve as inputs to a perceptron-like recognition system for detection of man-made objects.

6.3 Recognition

Additional investigation of object recognition capabilities were continued using the CAL photo input system and IBM-704 computer. The earlier work of recognition and training of intentionally distorted objects, similar to that produced by annular or K-S filtering,[10] gave over-all object recognition results of 98.7% after training on a 720 pattern test set for four types of airplanes, ships, buildings, and tanks. The perceptron size was 500 A-units, and had 20 positive and negative connections per A-unit.

A comparison of the performance of a single-layer, perceptron-like device called an Adaline was made of error rates vs. size. This brought out through diminishing perceptron-size tests that a perceptron of 100 A-units with 40 connections per A-unit, or 100 weights and from 2000 to 4000 connections is comparable to an Adaline with 1296 weights. It also clearly indicated that a two-layer linear discriminator can accomplish more difficult recognitions than a single-layer discriminator such as an Adaline.

Additional tests were made to study distortion effects caused by isolation and standardization where figures are torn into several pieces. A 500 A-unit perceptron was trained to recognize all aircraft for a large sample set; and a different set of 866 patterns was then used to test performance. Only 4.8% classification errors were made; this compares to zero errors for previous tests without isolation and standardization.

A measure of information transfer for each A-unit was investigated for improvement of A-unit connection efficiency, and used the joint probability distribution of A-unit activity and pattern classification to determine bit rates/A-unit. In a class of airplane discrimination tests, it was determined that some A-units [illegible]smitting up to .38 bits per pattern.

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Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

SECTION 7.0

RECOMMENDATIONS FOR FUTURE RESEARCH

The research effort of the past year, together with the previous Phase I, II and III investigations, have established a significant background of knowledge for the application of perceptron concepts to photo interpretation. The program efforts to date have evaluated a number of techniques for accomplishing the basic steps to photo preprocessing (object detection, isolation and standardization), property measurement, and the classification function.

The recent results in electro-optical spatial filtering for culture detection, whole-photo classification, and recognition should be continued by the further development and perfection of a more sophisticated experimental model. The spatial filtering preprocessing property extraction work should be continued and the derived outputs used as inputs to a perceptron recognition system. Additional experimentation of property extraction for whole-photo classification and object recognition is necessary to increase the performance, accuracy and degree of automaticity of this photointerpretation operational aid. When the preprocessing and recognition performance for the system have been improved through further experimentation, a new design should be conceived and detailed to implement the desired characteristics in a high-speed, parallel, electro-optical machine.

The recommended steps in a future program have been submitted to the Geography Branch of ONR as a proposal[11] for an extension, and are similar to those listed here.

7.1 Optical-Electronic Spatial Filtering

Determination of the feasibility of optical-electronic spatial filters for culture detection should continue utilizing the experimental set-up "B" described in Section 4.3 and using actual imagery as an input. The derived properties of the spatial filter output should be either (a) digitized for direct insertion into the CAL IBM-1401/7044 computer or (b) digitized for insertion

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into the CAL experimental linear discriminator (CLARA)*, which is presently being developed by CAL internal funds. Results of the spatial filtering plus recognition system, if favorable, should be used for development of a culture detection model.

7.2 Whole Photo and Object Classification

The spatial filtering experimentation should be performed using actual imagery and techniques suitable to the whole photo and object classification problems. The derived spatial filtering properties should be used in training and recognition experiments for determining the size required and accuracy of the perceptron-type mechanism. Full gray scale imagery and nonsupervised training techniques should be items to be included in the investigation.

7.3 System Design of Improved Model

Based upon the success of the two steps above, an improved version of a preprocessing and recognition model should be designed as a prototype for operational aid to the photo interpretator. Parallel design of electro-optical processes should be considered with high-speed culture detection, whole-photo classification, and object recognition capability.

The CLARA special-purpose computer should be utilized for actual recognition experimentation. Design characteristics for the photo interpretation operational aid for image centering, training modes, and machine size vs. accuracy should be obtained rapidly from the CLARA machine.

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* The Cornell Learning and Recognizing Automaton (CLARA) is under construction and will be available near the end of 1964 for pattern recognition experimentation. CLARA will consist of an off-line digitally implemented linear discriminator capable of being organized as a perceptron, an Adaline, or a wide variety of other similar classification systems. The logical flexibility of CLARA will also permit a modest general-purpose capability. A wide variety of input/output media are provided, including optical, magnetic tape, and manual entry.

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SECTION 8.0

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Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

APPENDIX A

A-1 Light Level Calculations for Optical Spatial Frequency Analyzer

No satisfactory theory exists which permits the direct computation of illumination in the frequency phase of optical spatial frequency analyzers. The best one can do is scale from experiments with similar devices.

All other things equal, the spectral power density p (watts/sq/mm)^2, at a given frequency (ν_x, ν_y) will be proportional to the input power P (watts). Also, for pictures of the same contrast and average density, the upper envelope of the spectral power density is approximately proportional to $(\nu_x^2 + \nu_y^2)^{-5/4}$. Thus, we have:

$$\bar{P}(\nu_x, \nu_y) \approx KP(\nu_x^2 + \nu_y^2)^{-5/4}$$

The irradiance on the detector, in watts/(mm)^2 is the spectral power density multiplied by the scale factor squared, where the scale factor is the ratio between the spatial frequency and the distance which represents it. The response of the detector may be a function of the wavelength of the radiation used. Thus, we have the envelope of the response at a spatial frequency given by:

$$\bar{R}(\nu_x, \nu_y) = KPs^2 \rho(\lambda)(\nu_x^2 + \nu_y^2)^{-5/4}$$

where s = scale factor,

$\rho(\lambda)$ = relative response over wavelength.

The constant K, in terms of the noise level of the vidicon, is to be found experimentally, by the rearrangement of the above to:

$$K = \frac{N(\bar{\nu})^{5/2}}{Ps^2 \rho(\lambda)} \tag{A-1.1}$$

where N = noise level of tube

$(\bar{\nu})$ = greatest spatial frequency at which a signal was visible.

For the experiment with a mercury arc source, we had

$$\bar{\nu} = 5.3 \text{ cy/mm}$$
$$P = 2.86 \times 10^{-5} \text{ watts}$$
$$s = 5.6 \text{ cy/mm/mm}$$
$$\rho(\lambda) = 0.05 \ \mu A/\mu W$$

where $\rho(\lambda)$ was taken from RCA data, $\bar{\nu}$ and s are measured fairly readily, and P was measured as described in a separate section.

Hence $K \cong N \cdot 1.5 \times 10^6$.

For the experiment with a laser,

$$\bar{\nu} = 11 \text{ cy/mm}$$
$$P = 1 \times 10^{-3} \text{ watts}$$
$$s = 3.5 \text{ cy/mm/mm}$$
$$\rho(\lambda) = .0225 \ \mu A/\mu W.$$

Hence $K \cong N \cdot 1.5 \times 10^6$,

where the data were determined as before, except that the power was taken from the manufacturer's specifications.

For an operating system, the fundamental design variables are the maximum spatial frequency to be observed $(\bar{\nu})$, and the signal-to-noise ratio at this frequency and the quantity to be calculated is the required source power. Equation (A-1.1) relates maximum spatial frequency to power for a barely visible signal (signal-to-noise ratio assumed to be unity). This equation, and the constants derived above, have been used to calculate the following table:

Approved For Release 2004/03/17 : CIA-RDP80B01139A000500240008-5

TABLE A-1

LASER POWER REQUIREMENTS

Maximum Spatial Frequency (cy/mm)	Signal to Noise Ratio (db)	Required Laser Power (milliwatts)
20	10	13.3
30	10	36.8
20	20	133
30	20	368

Laser power outputs as large as 40 milliwatts are commercially available at present. In addition, it is possible to increase the vidicon sensitivity by the use of slower frame rates. There is some reason to believe that the vidicon used in these experiments had been damaged, and thus was less sensitive than a typical tube of this type, so that the figures presented above are conservative.

A-2 Calibration of Brightness Meter

The "spectra" brightness meter is set up to read directly the brightness of a distant object in ft.-lamberts. This is based on the equation $E_D = B$ where

E_D = illumination on detector

B = brightness of object

Ω = solid angle subtended by lens from detector in use,

E_D is measured and B is computed by proper scaling of the meter scale. For a collimated beam of light, all of the energy (except for losses which have also been taken care of in picture meter scale calibration) falling on the lens will arrive at the detector. Thus

$$E_D A_D = E_L A_L$$

where

A_D = area of detector

E_L = illumination on lens

A_L = area of lens.

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Solving this equation,

$$E_L = \frac{A_D}{A_L} B.$$

By letting α = 1/2 field angle and Q = lens to detector distance, the result is that $A_D = Q^2 \pi \sin^2\alpha$, and $\Omega = A_L/Q^2$.

Substituting $E_L = (\pi \sin^2 \alpha) B$ with B in candles/ft^2, E_L will be in lumens/ft^2. In order to convert the meter readings (R) from ft - lamberts to candles/ft^2, it is necessary to divide by $B = R/\pi$.

Then $E_L = \sin^2 \alpha R$.

The conversion factor from lumens/ft^2 to lumens/m^2 is 10.76 so that

$$E\,(\text{lumens/meter}^2) = 10.76 \sin^2 \alpha R.$$

For the Hg green light source, there are 671 lumens per watt, so that

$$W = \text{irradiance} = \frac{10.76 \sin^2 R}{671}.$$

α was measured and found to be 44 ft. Therefore $H\left(\frac{\text{watts}}{\text{m}^2}\right) = 2.627 \times 10^{-6}$ R (ft lamberts) with a 1/8 mm pinhole. With a 628 mm focal length collimator, the meter read 980 ft lamberts which means that the irradiance was

$$H = 2.57 \times 10^{-3} \text{ watts/m}^2.$$

The area of the object plane is $= \frac{\pi}{4}(.119)^2$ because its diameter is 119 millimeters. Thus the power supplied was $P = 2.86 \times 10^{-5}$ watts.

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APPENDIX B

SCANNING DISC CONTROL ELECTRONICS

B-1 Control Block Diagram Description

FigureB-1 shows the major elements within the control electronics package used with the Nipkow scanning disc. The required operations are these:

1) Sense the start of each of 10 horizontal scan lines and generate a horizontal scan ramp voltage.

2) Derive a pulse coincident with the start of the 10 line raster and generate a vertical scan ramp voltage.

3) Provide control signals, interlocked with the slide projector and capable of manual override, to advance the slide magazine after a raster scan, and to hold off the next scan until the slide projector has finished the filter change cycle.

4) Generate a Z-axis (binary) modulation signal with a variable threshold from the photomultiplier amplifier output.

The mechanization uses conventional transistor switches, diode gates, set/reset flip flops, a holdover multivibrator, and a standard CRO.

The system (see Figure B-1) works like this:

1) A fixed lamp illuminates one side of the scanning disc at the radius of the synchronization holes.

2) As each hole rotates past the lamp, light reduces the resistance of photoresistor, and the PNP transistor switch following "opens up" to provide a -6 volt pulse (called "HOLE") lasting for as long as light energizes the photoresistor.

3) The first HOLE pulse sets the FRAME holdover multivibrator; and each succeeding pulse sets the timing capacitor again to the maximum negative level. As this capacitor discharges to a positive level, a switching level is finally exceeded (unless

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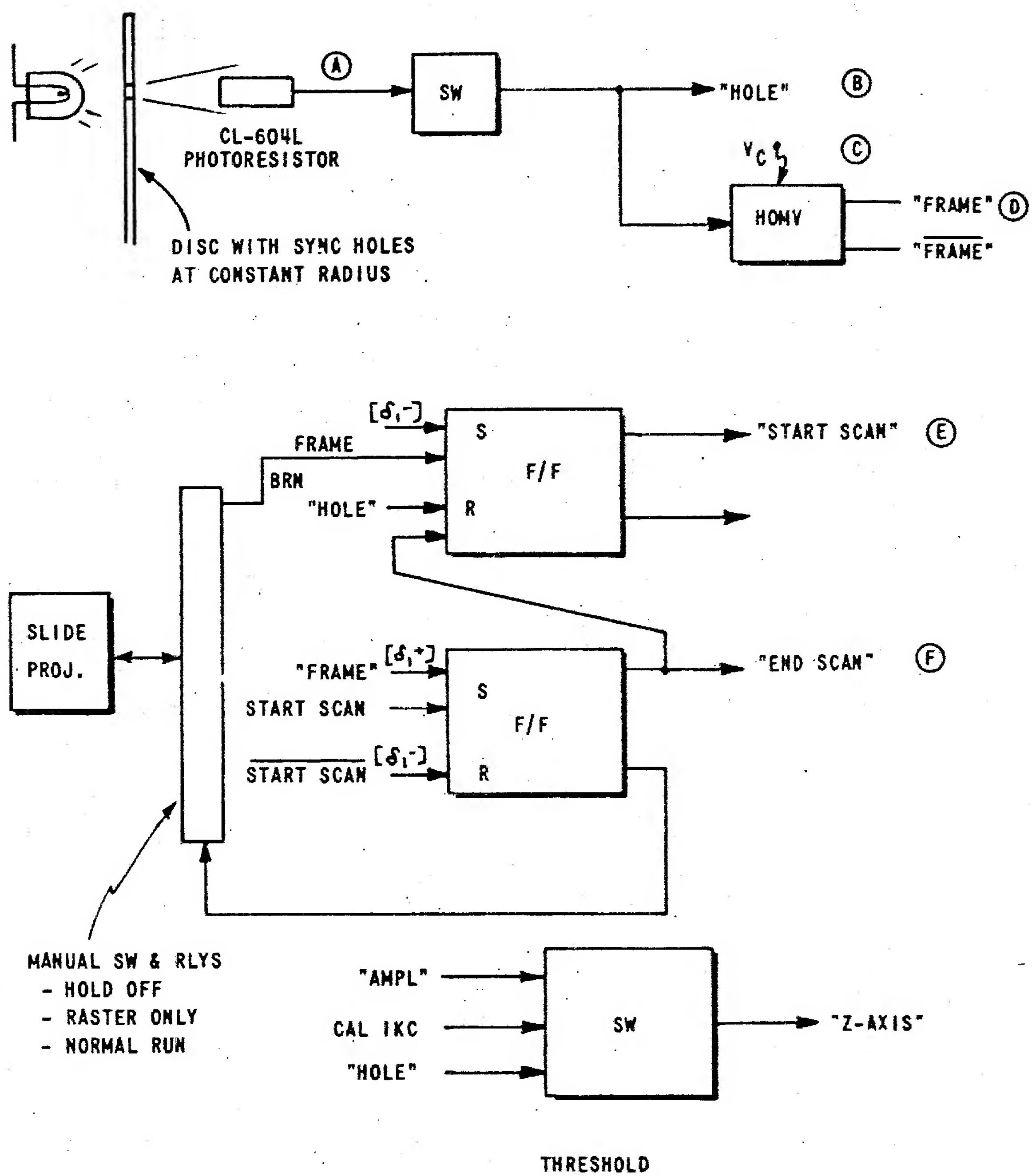

Figure B-1 BLOCK DIAGRAM OF ELECTRONIC CONTROL FOR SET-UP "B"

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another HOLE appears). After the last hole in a disc rotation, the FRAME element switches back to the stable state. The leading edge of FRAME marks the leading edge of the first synchronization hole, and the trailing edge of FRAME, a preset constant time after the last hole.

4) Two control flip flops are clocked by the above signals and provide these control combinations:

a) $\mathrm{STARTSCAN} \cdot \overline{\mathrm{ENDSCAN}}$ = display this raster

b) $\mathrm{STARTSCAN} \cdot \mathrm{ENDSCAN}$ = advance the slide projector magazine

c) $\overline{\mathrm{STARTSCAN}} \cdot \overline{\mathrm{ENDSCAN}}$ = do nothing

5) X and Y raster generating signals derive from standard CRO ramp generators. The following signals provide triggers (the symbol δ_1^- means take a negative-going pulse from a differentiator):

a) trigger X = $\delta_1^-[\mathrm{HOLE} \cdot \overline{\mathrm{ENDSCAN}}]$

b) trigger Y = $\delta_1^-[\mathrm{STARTSCAN}]$

6) The Z-axis signal unblanks the CRO beam during the period between synchronization holes if the amplified photomultiplier output exceeds a manually set threshold. A 1000 pulse per second square wave (the CRO calibrate signal) modulates this signal, and is required because the Z-axis input is a-c coupled. The threshold circuit switch operation may be summarized in:

a) $\overline{\mathrm{HOLE}} \cdot \left[(\mathrm{AMPL} \cdot \mathrm{CAL}_{\mathrm{IKC}}) \geq \text{threshold}\right]$

B-2 Timing Signals during Scan

Figure B-2 shows photos of signal voltages within the control electronics used in experimental set-up B. From top to bottom (in both photos which have different time scales), the signals are (the letters also refer to points in block diagram, Figure B-1):

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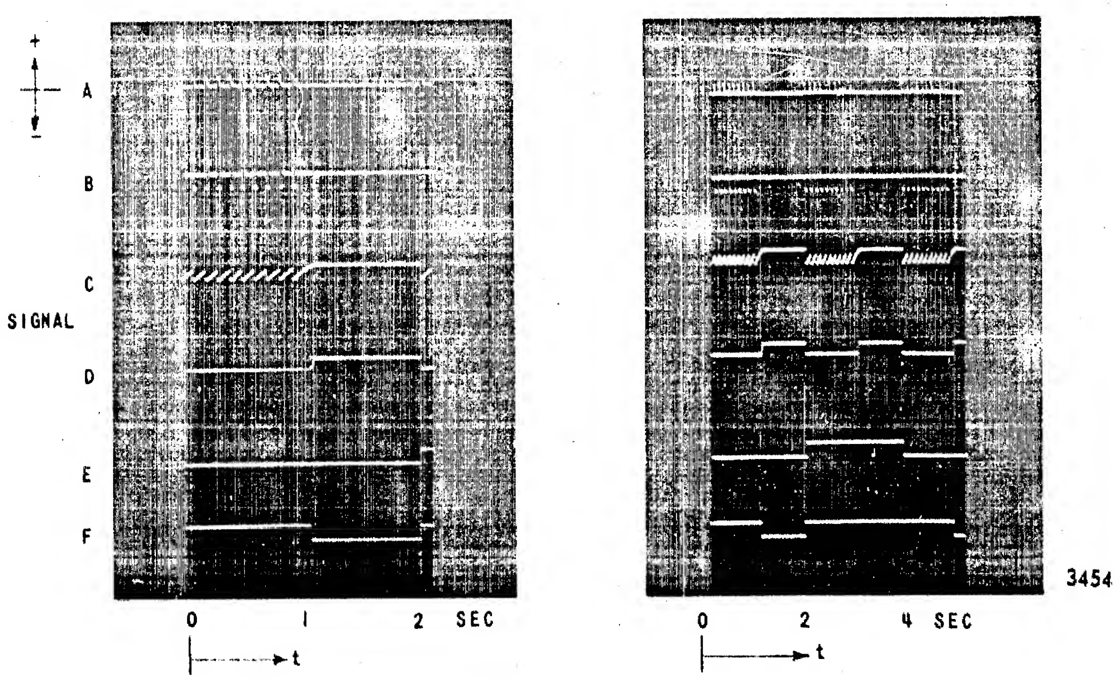

Figure B-2 SIGNAL VOLTAGE PHOTOS OF CONTROL TIMING SIGNALS

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A - The voltage across the load resistor in series with the input photoresistor (Clairex CL-604L).

B - The output of the PNP transistor switch: between synchronization holes the switch output is at zero volts; while the hole, light source, and photoresistor are aligned, the output is minus six volts. Call this signal "HOLE."

C - The voltage across the timing capacitor within the "FRAME" holdover multivibrator. (A holdover multivibrator is also called a "missing pulse detector.") Note that the time constant used prevents discharge to a switching level until after the last HOLE in a given rotation of the scanning disc.

D - The output voltage of the holdover multivibrator (HOMV) called "FRAME."

E - The STARTSCAN flip flop (F/F) output. This element sets to minus six volts when (1) the slide projector has completed a change cycle and is ready, (2) the manual control switch is at the "RASTER ONLY" or "NORMAL RUN" position, and (3) the FRAME signal undergoes a negative transition $\left[\delta_1^-\right]$. STARTSCAN resets with HOLE and ENDSCAN (after the slide projector has advanced).

F - The ENDSCAN F/F output. This element sets to minus six volts when STARTSCAN = 1 and FRAME changes from zero to plus six volts (after the last hole of the scanning disc rotation). This element resets immediately following the STARTSCAN reset.

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